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ORIGINAL ARTICLES.

The Scotland Beds of Barbados.

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(PLATES XXI–XXIV.)

BARBADOS, occupying as it does the position of the most easterly and isolated and the furthest out in the Atlantic Ocean of all the West Indian Islands, deserves special attention from geologists. Its rocks consist essentially of three units each separated from the other by an important unconformity, namely in descending order the Coral Rock, the Oceanic Series, and the Scotland beds.

The most conspicuous formation is the Coral Rock which covers six-sevenths of the island and rises in a number of well-marked terraces with intervening plains or gentle slopes up to the highest points, which occupy a curved ridge 1,000 to 1,130 feet in height, extending for some miles around the north-eastern area. The portion of the island below the Coral Rock escarpment where the older beds are exposed is known as the Scotland district, a name given to it by the early settlers on account of its rugged character.

THE CORAL ROCK.

An excellent account of the Coral Rock and other formations of Barbados has been given by Sir J. B. Harrison and A. J. Jukes-Browne[1] and I can add but little to their account. My observations entirely support their view that the Coral Rock is of Pleistocene and Recent age. Even at the highest levels of about 1,000 feet, where most of the shells and corals have been dissolved away and the calcite of the rock recrystallized as a dense mass, one can recognize such familiar recent mollusca as *Strombus gigas*, *Livonia pica*, *Astralium imbricatum* and other large shells which have here and there survived the dissolving process. The deposition of this thick and elevated and in places strongly altered mass of Coral Rock evidently represents a considerable period of geological time, but it seems to be entirely a Pleistocene feature.

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[1] *The Geology of Barbados.* An explanation of the Geological Map, published by the Barbadian Legislature, 1890.

THE OCEANIC SERIES.

As regards this series I have little to add to the stratigraphic and microscopic studies of Harrison and Jukes-Browne. Large fossils are exceedingly rare in these beds except at one or two localities. One of these is at Bissex Hill, where an outlier of the Oceanics rests on Scotland beds. It seems to indicate a somewhat shallow water phase of the Oceanics and comprises several beds of light-coloured limestone some of them compact, massive, and blue-hearted, others thin and friable and made up of small fossils. These include *Globigerinae*, echinoderm spines, small turbinate corals, shark's teeth, etc. Mollusca are rare and poorly preserved, and I have not been able to gather much information from them. I do not think that beds of the Bissex Hill type pass up into the Coral Rock or are in any way related to it.

Mr. R. J. L. Guppy recorded from this locality *Echinolampas anguillae* Cotteau which should be Oligocene if the identification were correct. The famous supposed deep water echinoderm, *Cystechinus crassus* Gregory,[1] was found in a well sinking at Haynesfield and is a fossil of comparatively recent aspect. The age of the Oceanic Series is still in doubt, but from their comparatively slight disturbance and from other facts I am inclined to think they are not older than Pliocene. In this case they may be equivalent to the Manchioneal beds or Pteropod marls of Jamaica, but there is not yet any fossil evidence to support this correlation. Perhaps some evidence on this point may be forthcoming in the future.

THE SCOTLAND BEDS.

The present paper is intended mainly as a contribution towards determining the age of the Scotland beds, the great and thick series of very strongly folded, contorted, and faulted rocks that forms the basement of the island, and doubtless underlies the Coral Rock and Oceanics everywhere. A very good general description of the Scotland Beds has been given by Harrison and Jukes-Browne, and I have no doubt that the sequence of the various clays, sandstones, grits, and conglomerates that they quote on pages 12 and 13 is essentially correct for the part of the Scotland area to which it refers, but a complete enumeration of the rather monotonous alternation of beds that form the Scotland series has not yet been published.

These authors, from the few fossils they observed tentatively express the view on page 15, that the Scotland beds are Miocene in age, a conclusion that is revised in the present paper, as the fossils are certainly of rather high Eocene aspect. They also estimated the thickness of the Scotland beds at about 500–600 feet, but I imagine the thickness of the series to be very much in excess of this.

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[1] *Q.J.G.S.*, xlv, 1889, pp. 640–50.

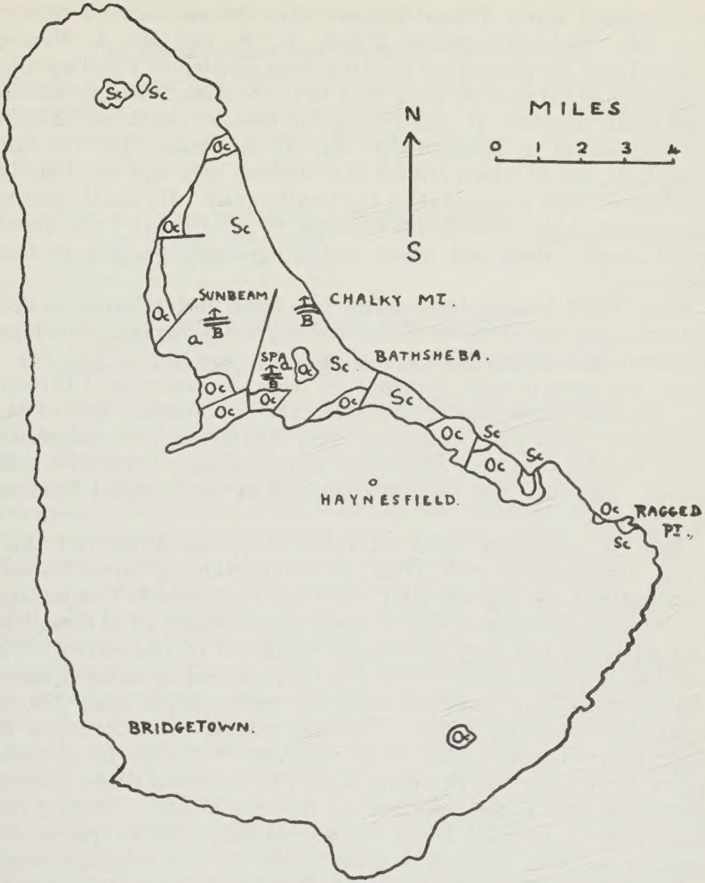

FIG. 1.—Locality sketch map of Barbados. Sc., Scotland beds; Oc., Oceanics; the remainder is Coral Rock. $\frac{\uparrow}{\text{B}}$ indicates roughly the position of the strike and dip of the fossiliferous conglomerate bed "b". The position of the two occurrences of the fresh-water sandstone bed is indicated by "a". The faults in the Scotland district are taken from the map of Harrison and Jukes-Browne, but there are evidently other faults not yet mapped. Haynesfield is the place where *Cystechinus crassus* Gregory was found in Oceanics below the Coral Rock. Views on Pl. XXI are taken from Chalky Mount and Ragged Point.

Neither the base nor the top of the Scotland Series can be observed in the small area afforded by their exposure, and faulting and zigzag folding of the thinner and softer beds makes their thickness very difficult to estimate, but I think it cannot be less than 2,000 feet at the least.

Before detailing my observations on the sections and fossils of the Scotland Series I must acknowledge the assistance I received from Mr. Beeby Thompson, F.G.S., F.C.S., and Mr. A. Menzies. Before I had the pleasure of meeting these gentlemen I had searched several times for fossil-bearing beds in the Scotland district but with very little success. It was during his detailed work on the area for purposes of oil location that Mr. Menzies traced the two chief fossil beds, one of which crosses the Scotland area and was found to be of great value in elucidating the stratigraphy. He kindly pointed out several of the fossiliferous localities to me so that I was able to spend many subsequent hours in the agreeable pastime of fossil collecting.

Other fossil-bearing beds occur, but those just referred to seem to be the only two in the whole series that yield recognizable mollusca. Harrison and Jukes-Browne, for instance, mention a bed No. 4, rather low down in their sequence on page 13, consisting of 18 inches of calcareous sandstone with broken shells. Another bed of concretionary sandy grit containing very fragmentary unrecognizable shells can be seen near the shore some distance north of Chalky Mount. The two chief fossil-bearing beds of the Scotland Series are as follows :—

Bed " *a* ".—A very hard indurated sandstone a few feet thick, often impregnated with pitch or oil containing large Lamellibranchiata (*Unio*, *Cyrena*, etc.), and large Gasteropoda (*Ampullaria*) and some smaller fossils also of fresh-water aspect, all of them fresh and unbroken but very difficult to break out of the matrix. This bed has not been observed in situ but is found as isolated masses that seem to have travelled down the valley slopes some distance from their point of origin. Several masses of it occur on the slope below Turner's Hall where portions of it may be in place ; and a large piece full of fossils is seen in a stream below the conglomerate next to be described on the Spa estate. Judging from their present position these masses should occur in place some distance, possibly 150 feet or more, below the bed of conglomerate.

Bed " *b* ".—A beach-like or shallow-water bed of unassorted conglomeratic material, which generally yields numerous fossils, the larger ones invariably in fragments, the smaller ones either quite fresh or more or less rolled and broken. It occurs apparently rather above the middle of the great mass of grits, shaly sandstones, and other beds that build up the Scotland Series, but it generally shows an angular discontinuity with the more regularly bedded series above and below it. It crops out at various places in the Scotland area, and seems to be the bed that is mentioned by Harrison and Jukes-Browne in their sequence on page 13 as bed No. 11, and again on page 15 as occurring on the Spa estate. I have examined this fossiliferous conglomerate and the beds above and below it at the following among other localities. It is remarkably rich in species, and every visit seems to yield a new addition to the list, but the specimens as a rule are somewhat small.

DESCRIPTION OF LOCALITIES.

The Ridge between Spa Estate and Cane Garden.

The fossiliferous bed "*b*" here forms part of a steep and precipitous ridge made up largely of the more resistant conglomerate which strikes west-north-west and east-south-east, and dips almost vertically. The sequence appears as follows in descending order :—

		Thickness in feet.
1.	White sandstones with marly partings and alternations of shaly sandstones	Several hundred.
2.	Thick dark irregular sandstones	20 (?)
3.	Impure nodular sandy limestone . . .	3
4.	Conglomerate with fossils	12–20
5.	Coarse dark petroliferous grits and sandstones, the grains rounded	100 (?)
6.	Sandstones and shales with ferruginous concretions	Several hundred.

The conglomerate (No. 4) is made up chiefly of rounded quartz pebbles and sand grains and pieces of derived sandstone and shale. Small claystone nodules of round or elongated form often broken also occur, some of which show a concentric structure while others have grown partly round crab claws, or more rarely around a shark's tooth or other organism. Oyster shells of a dark colour, broken and rolled, sometimes embedded in a sandstone matrix, evidently derived from a somewhat older dismantled formation, are also found. Small rolled pieces of sandstone or clay limestone full of Foraminifera (*Nummulites* and *Orthophragmina*) derived from an older, but apparently not very much older bed together with small rolled corals and rounded masses of *Lithothamnion* are also rather frequent. Shells of various mollusca occur sharp or more or less rolled and are evidently contemporaneous with the conglomerate bed. Although a careful search was made no trace of igneous or metamorphic derived rocks was seen in any of the Scotland conglomerates, nor any trace of derived fossils except those from the above-mentioned rather older Eocene bed or series of beds which must have been undergoing denudation during the deposition of the conglomerate.

The Ridge near Sunbeam Estate below the foot of Turner's Hall Wood.

The fossiliferous bed here comprises several bands of conglomerate each a few feet thick, made up of pieces of quartz and clay-limestone and other material interbedded with shales and sandstones. The constituents of the conglomerate are very similar to those at Spa. The series strikes east-north-east and west-south-west and dips at very steep angles about north-west. The sequence appears as follows in descending order :—

1. Sandy shales.
3. Very thick white sandstones with shales.
3. Conglomerates with fossils.
4. Sandy shales with ironstone nodules and large selenite crystals.

The conglomerate (No. 3) in this locality is seen twice on the path which leads along the ridge, the repetition is apparently due to faulting.

Ragged Point.

Beds low down in the Scotland Series are well seen at Ragged Point lighthouse in the south-east corner of Barbados, where they are partly covered by a thin layer of Coral Rock, the Oceanics being absent just here. They dip north-west at about 30°, but no fossils were seen in any of them. I enumerated the beds exposed in this locality as follows :—

	Approximate thickness in feet.
Coarse sandstones with rounded grains	60
Sandy shales with ferruginous partings	10
Sandy blue shales	10
Fine-grained well bedded grit	35
Sandy blue shales	12
Ferruginous grit	5
Sandy blue shales	10
Ferruginous sandstone	15
Sandy blue shales	5
Soft grit	2
Soft blue shales	3

Chalky Mount

There is nothing chalky in the composition of the rocks of this locality, but the thick precipitous and jagged steeply dipping white sandstone that forms the highest part of the elevation seems to have given rise to the name. The beds strike approximately between east and west and north-east and south-west, and dip at 70°–80° to the north. The sequence is as follows :—

	Thickness in feet.
1. Coarse white sandstone with gritty beds and ferruginous partings and concretions	over 300
2. Alternating shales and sandstones	30
3. White sandstone	20
4. Fossiliferous conglomerate bed	12–20
5. Alternations in thin bands of brown or white soft sandstones and beds of coarse grit with thin bands of Selenite crystals along the bedding planes	over 300

The conglomerate band here is compact and resistant and is made up of elongated rolled masses of sandstone up to a foot in length, rolled pieces of a sandy limestone with rather large *Ostrea*, and here and there small rounded fragments of rock containing small *Nummulites*. The contemporaneous fossils are similar to those at Spa and Sunbeam, but most of them are very friable and fragmentary. I collected a specimen of the variety of *Clavilithes solanderi* on the highest point of the conglomerate outcrop.

This easily recognizable fossil-bearing conglomerate maintains a thickness of 12–20 feet, and can be traced dipping steeply across the massif of Chalky Mount where it crosses the ridge and descends the precipitous southerly slopes and passes out to the sea under the waters of the Atlantic Ocean with a nearly vertical dip. North of Chalky Mount, along the coast a bed of coarse sandstone with broken fossils, mostly pieces of small *Ostrea*, occurs among beds some 200 feet higher than the white sandstone that forms the summit of Chalky Mount.

CONCLUSIONS AND CORRELATION.

The only recognizable fossils in the Scotland beds seem to occur at two small horizons not very far removed vertically from one another, so that conclusions as to the age of the beds refer to this portion of the series, while the very considerable thickness of beds above and below may be appreciably newer or older. The whole succession of beds seems to be of shallow water, and in some cases of estuarine origin. The hard sandstone (bed "*a*"), which has been mentioned as not occurring actually in situ, contains mollusca only of fresh-water origin. The conglomerate band (bed "*b*") is the only bed that yields well-preserved marine fossils, and the rolled condition of these, mixed as they are with a number of fresh- and brackish-water forms, points to the temporary invasion of a shallow water or littoral formation among the thick mass of unfossiliferous shales and grits above and below.

Exponents of the hypothesis of an Eocene continental land mass, "Antillia" or "Atlantis", may take courage from the occurrence of beds full of large fresh-water mollusca in this small and isolated island where now scarcely a stream and much less a river occurs. Curiously, however, no trace of any old rocks other than quartz pebbles has been observed in the Scotland Series so that the nature and position of the land whence the material was derived is unascertainable.

The fragmentary condition of many of the Scotland fossils and the small area afforded for collecting them makes it advisable to wait till more material is at hand before undertaking an exhaustive study of the fauna. Enough fossils have, however, already been collected to show clearly the general nature of the fauna and to indicate that it has much affinity with the Claiborne facies of Alabama, the Eocene of Nigeria found at Ameki, and the Lutetian and probably more to the Bartonian of Europe. The horizon of the fauna seems to be high in the Middle Eocene, or rather low in the Upper Eocene (Lutetian-Auversian-Bartonian). For the convenience of those geologists interested in West Indian stratigraphy I have made a somewhat preliminary determination of the fossils I collected and have photographed as many of them as space permits.

Comparison of this fauna with that of the Yellow Limestone in Jamaica is inconclusive because the Yellow Limestone fauna lived in situ, while the Scotland conglomerate is a washed-up or assorted shallow-water bed. The absence of *Velates*, large *Cerithia*, large *Lucinae*, and other forms common in the Yellow Limestone may be noted. In all probability the Scotland fossils belong to a higher horizon than the Yellow Limestone, and may correspond in time with some part of the lower White Limestone in Jamaica, such as the Claremont and Goschen beds which contain a prolific and unstudied fauna but which so far as I could observe, bears no similarity to that of the Scotland beds.

As regards Trinidad, the Scotland fauna seems to have some affinity with that found at Soldado Rock, an islet off the south-west corner of Trinidad characterized by *Venericardia planicosta* Lam. and correlated with the Midway Eocene of Mississippi, Georgia, and Alabama.[1] The Scotland fauna, however, appears to be considerably later.

DESCRIPTION OF FOSSILS.

Voluta cf. *pyruloides* Conr. (Pl. XXII, Fig. 3.)

Shell pyriform, smooth, with four very strong slanting anterior columellar folds. Length 34 mm., width 18 mm. From Spa. It resembles *Voluta* (*Caricella*) *pyruloides* Conr. (*De Greg.*,[2] pl. v, figs. 27 and 28), but the shell is narrower than in fig. 27 and the spine is broader and more elongated and the columellar folds stronger, closer together, and more anteriorly situated in the Barbados than in the Alabama form.

Voluta cf. *petrosa* Conr., var. *gracils* Lea. (Pl. XXIV, Fig. 4.)

This shell from Sunbeam closely resembles the above variety figured by De Gregorio (pl. iv, figs. 54 and 55). It has three or four small columellar folds.

Ficula (?) *scotlandica* sp. nov. (Pl. XXIV, Fig. 19.)

Shell of six whorls, fragile, with sharp spire, early whorls rounded with longitudinal ridges, the penultimate whorl keeled. The body whorl is large, tabulate and keeled below the suture, the middle part smooth, the anterior part decorated with very fine close-set parallel spiral ribs. Length 15 mm., width 8 mm. It comes near *F. juvenis* Whitf. of the Claiborne beds, but has no nodes and only one keel on the body whorl.

Mitra scotlandica sp. nov. (Pl. XXII, Fig. 2.)

Shell of seven or eight whorls, fusiform, sutures shallow, whorls rather flat, the last one somewhat tabulated below the suture, the anterior canal produced, aperture elongated. The inner lip has three or four thin and weak posteriorly directed folds, and is rather calloused posteriorly. The surface is smooth except for fine and close set but well-marked growth lines. Length 49 mm., width 19 mm. From Spa. This shell comes near *M. elongata* Lam. of the Lutetian and Bartonian of the Paris Basin, but the Barbados form has the body whorl relatively larger, the whorls flatter, and the sides of the spire more concave, the anterior canal narrower, and the folds on the inner lip more even in size.

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[1] Carlotta J. Maury, *Acad. Nat. Sci. Philad. Jour.*, ser. 2, vol. 15, 1912, pp. 25–112, pls. 5–13.

[2] Monographie de la Faune Éocénique de l'Alabama. *Annales de Géol. et Pal*, liv, 7me Livraison, 1890.

Mitra sp. (Pl. XXIV, Fig. 8.)

Several broken examples of a small smooth *Mitra* of thick and stumpy form with three or four acute plications on the inner lip occurred at Spa. They seem to have the shape of *M. angystoma* Desh. of the Bartonian (*Iconogr.*,[1] pl. xli, fig. 202–7). Another immature specimen with weaker labial folds resembles *M. labratula* Lam.

Clavilithes solanderi Grabau, var. *barbadensis* nov. (Pl. XXII, Fig. 8.)

A tabulate *Clavilithes* is a conspicuous fossil at Spa and on Chalky Mount, but it is rather scarce. The largest example is about 67 mm. long, and 27 mm. across the body whorl. The protoconch is small, and the nodose and concentrically striate ornamentation persists till the fifth whorl. The later whorls are more or less strongly tabulate; in the largest example I possess the whorls are rather inflated and the tabulation weak.

They bear considerable resemblance to some varieties of *C. solanderi* or *C. solanderi* var. *contabulata* in the Edwards collection in the British Museum, but when compared with specimens at an equal stage of growth the Barbados form seems to have a more slender spire, more tabulate whorls, and a smaller protoconch. Cossmann and Pissarro (*Iconogr.*, pl. lxv, fig. 198–1) refer to this large Bartonian form as *C. longaevus* Sol. *race solanderi*. Specimens of *C. longaevus* that I once collected in the Sables Moyens at Le Ruel near Paris have a wider spire, more sunken sutures, and a larger protoconch than the present shell. It may be compared also with *Clavella tabulata* Dickerson of the Eocene of Marysville Buttes, California (*University of California Publ. Geol.*, vol. vii, No. 12, 1913, pl. 12, fig. 7).

Clavilithes sp. (Pl. XXII, Fig. 6.)

In this specimen from Sunbeam the nodose and spirally striate condition persists longer, and traces of it are seen on the penultimate whorl. It may be a variety of the form just described.

Clavilithes sp. (Pl. XXII, Fig. 4.)

A young example of a form resembling *C. rugosus* Lam. or *C. tuberculosus* Desh. both of the Lutetian. It is from Spa.

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[1] Cossmann et Pissarro, *Iconographie complète des coquilles de l'Éocène des environs de Paris*, 1904–6.

Clavilithes sp. (Pl. XXII, Fig. 7.)

A long tapering shell with flat-sided whorls and shallow sutures is common at Sunbeam and occurs also at Spa, but all specimens have the apex and body whorl broken. The nodose ornamentation persists till the fifth whorl, but concentric striae are still seen even on the penultimate whorl.

Rhopalithes cf. *africanus* Newton. (Pl. XXII, Fig. 5.)

A specimen from Spa with the anterior part of the body whorl broken comes very close to this Nigerian form (*Geol. Surv. Bull.*, No. 3, 1922, pl. ii, figs. 9 and 10). The nodose condition persists on the sixth whorl and the fine concentric striae cover the whole shell which when complete has been about 56 mm. long and 18 mm. broad.

Siphonalia (*Pseudoneptunea*) sp. (Pl. XXIII, Fig. 22.)

Shell of six whorls rapidly increasing in size, sutures well impressed, the later whorls have about twelve rather broad sinuous longitudinal ribs crossed by fine spiral ridges. Length 20 mm., width 11 mm. From Spa. It rather resembles *S. angusticostata* Melleville of the Cuisian (*Iconogr.*, pl. xxxviii, fig. 186–13), but is larger, and has thicker and shorter ribs than the Paris shell.

Parvisipho (?) sp. (Pl. XXIII, Fig. 23.)

Shell of six whorls, elongated, sutures well marked, early whorls rather eroded, the last two whorls have about 22 rather coarse concentric spiral ridges, with intervening sulci of equal width. Growth lines are rather coarse. Length 22 mm., width 11 mm. From Spa. Most of the Paris Basin species of this genus are very small forms.

Siphonalia (?) sp. (Pl. XXIV, Fig. 20.)

Shell thick, spire elongated, sutures well marked with a concave smooth band below, body whorl with nine strong ribs crossed by eleven regular spiral ridges. Aperture without plication. Not unlike *S. variabilis* Lam. of the Lutetian (*Iconogr.*, pl. xxxviii, fig. 186–6), but larger and the ribs more pronounced. From Spa.

Siphonalia sp. (Pl. XXIII, Figs. 17 and 18.)

A rather variable form of this genus with fine, but more or less conspicuous concentric spiral striae is common at Sunbeam and less so at Spa. The height of the spire varies rather in the Barbados examples, the largest of which is 29 mm. long and 20 mm. wide. It has the general shape of *S. planicostata* Melleville of the Thanetian and Cuisian (*Iconogr.*, pl. xxxviii, fig. 186–2), but the ornamentation is more like that of *S. mariae* Melleville of the Thanetian (fig. 186–1).

Nasseburna cf. *calli* Aldrich. (Pl. XXIII, Fig. 21.)

Specimens from Spa agree closely with this species from Lisbon, Alabama, the type of which is refigured by De Gregorio (pl. vii, fig. 62). The spiral striae specially prominent below the suture and also towards the anterior end are more pronounced on some specimens than on others, the largest of which is 24 mm. long and 12 mm. wide.

Nassa sp. (Pl. XXIV, Fig. 15.)

This shell from Spa has the shape and ornamentation of *Buccinum* (*Nassa*) *confiscatum* (De Greg., pl. viii, figs. 20–1), but on the Barbados form the reticulate ornamentation weakens anteriorly, the aperture is more oval, and the shell more produced anteriorly.

Cancellaria cf. *stantoni* Dickerson. (Pl. XXIV, Figs. 45 and 46.)

Two specimens from Spa may be identical with the above species from the Eocene of Marysville Buttes in California (*Univ. of Calif. Publ.*, vol. vii, No. 12, 1913, p. 282, pl. xii, figs. 2*a* and *b*).

Pseudoliva scotlandica sp. nov. (Pl. XXIV, Figs. 1*a* and *b*.)

Shell of 5–6 whorls, moderately thick, sutures sunken, body whorl slightly concave below the suture, inflated about a third of the length in front of the suture. The surface is decorated with numerous fine irregularly spaced concentric ribs with shallow sulci between them, a deeper and wider sulcus occurs rather in front of the middle of the body whorl. The anterior channel is deeply cut and the umbilicus is wide and deep. Length 25 mm., width 15 mm.

In ornamentation and shape of the umbilicus it rather resembles *P. vetusta* Conr., var *moerens* (De Greg., pl. viii, figs. 39 and 40), a characteristic fossil of the Claiborne, but the Barbados shell is narrower and has a more elevated and wider spire.

Oniscia scotlandica sp. nov. (Pl. XXIV, Figs. 18*a* and *b*.)

Shell of five whorls; the later ones bear 8 or 9 irregularly spaced, coarse, longitudinal ribs crossed by about 12 spiral ridges. The outer lip is strong and thick, the inner lip expanded and papillated. Length 14 mm., width 5 mm. One specimen from Spa. This pretty little species recalls in miniature the recent *O. cancellata*, but its ribs are relatively stronger and more irregular and the shell stouter than in the living form.

Rostellaria (?) sp. (Pl. XXIII, Fig. 25.)

Shell of 8 or 9 whorls, bearing longitudinal rounded rather flexuous ribs, immediately below the suture there is a spiral ridge. Length up to 45 mm. Spa, six specimens. No trace of the outer lip remains but one specimen has the anterior end sharply prolonged, a feature which with the elongated aperture suggests some form of *Rostellaria*.

Cypraea (*Bernayia*) sp. (Pl. XXIII, Fig. 10.)

One specimen from Spa is not unlike *C. media* var *alabamensis* (De Greg., pl. ix, figs. 8–10), but the aperture in the Barbados form is narrower and the teeth on the outer lip smaller and finer. It resembles more *C.* (*Bernayia*) *bartonensis* Edwards, and is also very like a *Cypraea*, probably *Bernayia inflata* Lam., that I once collected in the Calcaire Grossier at Grignon.

Cypraea (*Cypraedia*) cf. *elegans* Defr.

A small specimen from Spa resembles this species in shape, but the ornamentation is almost entirely worn off. *C. elegans* occurs in the Yellow Limestone of Jamaica.

Cypraea sp. (Pl. XXIII, Fig. 16.)

A fragment of a shell from Spa with the anterior channel thickened and arched, and under surface flattened with prominent sulcidentate teeth on both lips. Similar shells occur in the Paris Eocene, but the fragment is too incomplete for comparison.

Sigaretus (*Sinum*) cf. *clathratum* Gmelin. (Pl. XXIII, Fig. 20.)

A fossil common at Spa seems to belong to this species and resembles closely specimens from the Eocene of Nigeria (R. B. Newton, *Geol. Surv. Bull.* No. 3, pl. ii, figs. 16 and 17). Newton states that this species characterizes the Middle and Upper Eocene of Britain and Europe, and discusses its affinity with a rather similar shell *Natica striata* Lea of the Eocene of Alabama, but De Gregorio's figures of this species (pl. 15, figs. 10–15) seem to have a lower spire and coarser ornamentation than the Barbados shell. It is 18 mm. high, and 17 mm. wide.

Natica (*Neverita*) cf. *mamma* Lea. (Pl. XXIII, Figs. 13, 14, 15.)

Five specimens from Spa 17 or 18 mm. wide, agree so closely with figures of this species (De Greg., pl. xiv, figs. 18–23 and 24) as to appear identical. The spire is low and the surface smooth with faint regular growth lines, but the degree to which the heavy callosity conceals the umbilicus varies. It is one of the most characteristic fossils of the Claiborne beds of Alabama.

Nativa (*Lunatia*) cf. *semilunata* De Greg. (Pl. XXIII, Fig. 12.)

A thick-shelled form from Spa, 13 mm. high and 12 mm. wide, resembles figures of this Alabama species (pl. xiv, figs. 31 and 32). The umbilicus is partly covered by a thin callosity.

Ampullina (*Euspira* ?) sp. (Pl. XXIII, Fig. 11.)

Shell rather solid, spire elevated, sutures deep, whorls rounded, with regular well-marked growth lines, aperture oval, callosity thin almost covering the umbilicus. Height 19 mm., width 15 mm. This specimen from Spa comes near to *Ampullina merciniensis* Desh. or *A. lignitarum* Desh. of the Cuisian and Sparnacian of the Paris basin.

Ampullaria sp. (Pl. XXII, Fig. 16.)

Many large Ampullariae occur in bed "*a*" at Turner's Hall and below Spa, but are very difficult to break out of the rock. One I collected is 86 mm. high and 84 mm. broad. The spire is rather elevated and the body whorl well inflated anteriorly, the umbilicus is nearly obsolete. Growth lines are irregular and foliaceous, the sutures rather deeply sunken and the shell is fairly thick. It resembles somewhat the recent *A. vermiformis* Reeve from Paraguay, but the sutures are less sunken and the umbilicus shallower. The recent *Pomella megastoma* Sow., also from Paraguay, has a more inflated body whorl and a still shallower umbilicus and an almost flat spire. The spire of the Barbados fossil is higher than that of the living *A. urceus* Müll. of Trinidad, but the shell is similarly thick and foliaceous.

Ancilla cf. *scamba* Conr. (Pl. XXIII, Fig. 19.)

One specimen of a small elegant *Ancilla* 18 mm. long and 8 mm. wide occurred at Spa. It resembles figures of *A. tenera* Conr. (De Greg., pl., iv, fig. 2) or more closely *A. scamba* Conr. (pl. iv, figs. 15 and 16). A comparison, however, with actual Alabama specimens would be necessary to establish the identity of the Barbadian shell.

Ancilla sp. (Pl. XXIV, Fig. 36.)

The figured specimen was found at Sunbeam; the apical portion of a larger one originally about 27 mm. long occurred at Spa. They are rather like *A. canalifera* Lam. of the Lutetian, but the Barbados shell has the spire shorter and more completely overgrown by callosity.

Ancilla (*Sparella*) cf. *dubia* Desh. (Pl. XXIV, Fig. 41.)

Small shells from Spa, 11 mm. long and 5 mm. wide, with the spire covered with callosity, are very like this Bartonian species from the Paris Basin.

Ancilla (*Sparella*) sp. (Pl. XXIV, Figs. 39 and 40.)

Specimens with the aperture about half the length of the shell and an almost completely calloused spire occur at Spa. Possibly more than one species is present. They resemble somewhat *S. arenaria* Cossm. of the Cuisian, but the spire is shorter in the Barbados form.

Olivella cf. *micans* Desh. (Pl. XXIV, Fig. 28.)

Four specimens from Spa resemble this form (*Iconogr.*, pl. xlvi, fig. 210-3) of the Bartonian and Lutetian. Length 18 mm., width 8 mm.

Olivella cf. *mitreola* Lam. (Pl. XXIV, Fig. 29.)

Some specimens from Spa, 14 mm. long and 5 mm. wide, are very like this Lutetian form.

Thersitea barbadensis sp. nov. (Pl. XXIII, Figs. 36, 37, 38, 39.)

Shell of seven whorls, the early ones gradually increasing in size, smooth, conical, and faintly sutured. The last whorl is very large, more or less strongly calloused below and also around the suture, the basal callosity extends backwards in some specimens completely enveloping the spire, in others the spire is quite free. The outer lip of the body whorl very thin, and always broken away, with a narrow anterior and posterior channel, the anterior one curving upwards. The last whorl is armed with a row of about seven more or less prominent pointed nodes below the calloused suture. Length about 32 mm., width 16 mm. A large rolled posterior portion is 24 mm. wide. About fifty specimens were collected at Spa, all more or less broken; sometimes only the calloused apical portion is found as a rolled pebble.

This species bears some resemblance to *T. gracilis* Coq. from the nummulitic beds of the Chaine de Negrine, Sud Constantinois (Cossmann, *Palaeoconch. comparée,* 4me Livraison, 1901, p. 21), but the callosity in the Barbados form is greater, and the spire shorter and more slender.

The affinity of this genus of Coquand which characterizes the Lower and Middle Eocene of Morocco, Algeria, and Tunisia is disputed; Cossmann thinks it comes near to *Clavella*, but J. Savornin concludes that it belongs to the Strombidae (*Bull. Soc. Geol. Fr.*, 4me Serie, xiv, 1914, p. 314).

Thersitea sp.

Three specimens of what appears to be another species of *Thersitea* occurred at Spa. The spire is elongated and conical and the last whorl is much less strongly calloused and noded than in the form just described. They are too much broken to allow a specific determination, but are not very unlike *T. gracilis* Coq.

Turbo (*Pareuchelus* ?) sp. (Pl. XXIV, Fig. 34.)

A small thin shelled nacreous species has five or six irregular spiral ridges on the body whorl crossed by exaggerated growth ribs forming a reticulate pattern. It is rather like *P. sigaretiformis* Desh. of the Lutetian (*Iconogr.*, pl. iv, fig. 31–1), but the Barbados shell has a larger spire and smaller aperture.

Nerita tricarinata Lam. (Pl. XXIV, Figs. 13 and 14.)

Two small specimens from Spa, one 9 mm. in width and 6 mm. high, and the other rather smaller, agree with this species. Cossmann and Pissarro illustrate examples from Cuise (*Iconogr.*, pl. v, fig. 38–4) but report that it occurs also in Lutetian and Bartonian beds. Similar specimens are found at Bracklesham and are illustrated by Edwards and Wood (*Eocene Mollusca*, vol. i, 1849–77, pl. xxxiv, figs. 22*a* and *b*).

Turritella spp. (Pl. XXIII, Fig. 27.)

An apical piece compares well with the young part of *T. carinifera* Desh. from Chaumont, but the ornamentation of the Barbados shell is rather sharper. A fragment of two whorls (fig. 27) recalls *T. hybrida* Desh. of the Cuisian and Thanetian. (*Iconogr.*, pl. xx, fig. 125–3.) Both are from Spa.

Turritella cf. *interposita* Desh. (Pl. XXIII, Figs. 28, 29, 30.)

Fragments of a solid and thick shelled form are common at Spa. The ornamentation varies owing to the extra prominence of one or other of the spiral ribs, but examination of a large number of specimens shows that the varieties merge into one another, and apparently represent one species. They agree rather closely with the above species reported from the Bartonian and also the Cuisian (*Iconogr.*, pl. xxi, fig. 125–18). The largest fragment has a diameter of 20 mm.

Mesalia sp. (Pl. XXIII, Fig. 26.)

A fragment from Spa has sunken sutures, the whorls concave and nearly smooth below the suture, but below that decorated with low, rounded, spiral ridges, which become obsolete on the body whorl.

Melanatria sp. (Pl. XXIV, Fig. 12.)

Shell small and slender, length 14 mm., sutures deep, whorls ornamented with ribs which end in rather sharp points below the suture, crossed by spiral ridges that cut the ribs into small nodes. From the conglomerate at Spa and also common in the fresh-water bed " *a* " below Turner's Hall.

Terebralia (?) spp. (Pl. XXIII, Fig. 24, Pl. XXIV, Fig. 10, Pl. XXIV, Fig. 33.)

A specimen (Fig. 24) 32 mm. long and 16 mm. wide resembles *T. sp.* from the Nigerian Eocene figured by Newton (*Geol. Surv. Bull.*, No. 3, 1922, pl. iv, fig. 10). It is also rather like a shell from the Port Maria beds in Jamaica that I called *Faunus vulcaniformis* (Geol. Mag., Vol. LXI, Jan., 1924, Pl. II, Fig. 1).

Another specimen (Fig. 33) is 22 mm. long and 10 mm. wide and resembles *T. sp.* from Nigeria, Fig. 11 on the plate quoted above. A third small form (Fig. 10) apparently belongs to the genus *Melanatria* or *Melanoides.* All are from Spa.

Melania sp. (Pl. XXIV, Fig. 25.)

A small form with eroded spire has the form of curved ribs seen on the recent *Tiara tornatella* Lea of the Philippines.

Lithasia ? sp. (Pl. XXIV, Fig. 3.)

Shell thick, stumpy, the earlier whorls eroded, sutures shallow, sides rather concave; below the sutures there is a row of blunt nodes, columellar callus small and anteriorly situated. The lip is broken, but the growth lines sweep forward anteriorly and the general shape suggests the recent North American genus *Lithasia.* Length 19 mm., width 10 mm. From Spa.

Tympanotonus sp. (Pl. XXIV, Fig. 5.)

Shell thick, with tapering spire, ornamented with blunt nodes which disappear on the later whorls. The body whorl has about six rounded concentric ridges of variable size. Inner lip thinly calloused. Length 25 mm., width 9 mm. Among Paris Basin forms it bears some resemblance to *T. gradatus* Desh. from Cuise. (*Iconogr.*, pl. xxix, fig. 151 bis 12.)

Cerithium (*Tiaracerithim*) sp. (Pl. XXIV, Fig. 16.)

Shell with tapering spire and later whorls with a nodular ridge a little below the suture. The outer lip broken. Length 27 mm. From Spa.

Cerithium (*Vulgocerithium* ?) sp. (Pl. XXIV, Figs. 26 and 27.)

Shell of nine whorls, the early ones smooth, the later decorated with a shallow broad round-bottomed groove about midway between the sutures. Aperture sub-circular, sutures shallow, shell rather flattened basally with a columellar fold. Length 22 mm., diameter 9 mm. From Spa.

Bayania sp. (Pl. XXIV, Fig. 2.)

Shell elongated, thick, solid, sutures shallow, inner lip slightly callous, the anterior part of the last whorl with five or six low rounded spiral ribs. Length 25 mm., width 9 mm. From Spa. This has rather the shape of *B. lactea* Lam. which occurs in the Cuisian, Lutetian, and Bartonian beds of Paris, but the anterior spiral ribs distinguish it.

Bayania sp. (Pl. XXIV, Fig. 11.)

Shell thick, stumpy, sutures shallow, whorls smooth, rounded, with faint growth lines and traces of ribbing on early whorls of some specimens; inner lip has a thin callosity. Rather like *B. triticea* Fér. (*Iconogr.*, pl. xix, fig. 121–3), but the Barbados shell seems thicker and more solid. Length 16 mm., width 8 mm. From Spa.

Pleurotoma sp. (Pl. XXIV, Fig. 35.)

Broken apical fragments from Spa have a single smooth or slightly noded ridge, above which the whorls are broadly concave. It appears to have some resemblance to *P. engonata* Conr. (De Greg., pl. ii, fig. 42), but has a higher spire and a blunter ridge.

Surcula ingens Mayer-Eymar. (Pl. XXII, Fig. 1.)

About twenty specimens from Spa and Sunbeam seem to be identical with this species and closely resemble examples from Nigeria described by Newton (*Geol. Survey Bull.*, No. 3, 1922, p. 20, pl. ii, figs. 6–8), but are mostly much smaller. The largest fragment, a detached body whorl 35 mm. in diameter, considerably smaller than the large Nigerian specimens, seems to be derived from an older bed. The smaller ones in the conglomerate bed show some variation in the height of the spire and sharpness of the varices and strength of the faint spiral ridges on the whorl above and below the varices.

In Egypt it occurs in the Upper Mokattam beds (=Bartonian) of the Fayoum. A rather similar shell *S. occidentalis* Woods,[1] occurs in the *Clavilithes* beds near Negritos in Peru.

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[1] *Geol. of Tertiary and Quaternary in N.W. Peru*, 1922, p. 106, pl. xvi, figs. 7–10.

Surcula barbadensis sp. nov. (Pl. XXII, Fig. 10.)

Shell of about nine whorls which are deeply sutured and strongly keeled; a smooth concave platform occurs above the keel, the edge of which bears a line of small sharp slanting nodes. The body whorl tapers rapidly in front of the keel and has concave sides which are decorated with about eighteen concentric sharp ridges massed together anteriorly. Length 42 mm., diameter 16 mm. From Spa.

This shell belongs to the group represented by *Surcula* (*Ancistrosyrinx*) *terebralis* Lam. from the Lutetian (*Iconogr.*, pl. l, fig. 223 bis 6) but the Barbados shell is larger.

Surcula barbadensis var. *spirata* nov. (Pl. XXII, Fig. 11.)

Another shell occurs at Spa and seems to be a variety of that just described. The spire is more drawn out and the platform less concave, the ridge blunter, and the spiral lines in front of it coarser and growth lines more marked. The only two examples I found are imperfect.

Pleurotoma (*Clavatula*) sp. (Pl. XXIV, Fig. 17.)

A stumpy conical shell from Spa 15 mm. long and 8 mm. wide resembles *C.* (*Trachelochetus*) *desmia* Edwards from the Bartonian (*Iconogr.*, pl. l, fig. 222–1), and is also not unlike *Pleurotoma congesta* Conr. (De Greg., pl. ii, figs. 58–61).

Pleurotoma (*Clavatula*) cf. *tupis* De Greg. (Pl. XXII, Fig. 9.)

Shell of eight or nine whorls, sutures shallow with a concave platform below, and a blunt rounded keel decorated with short rounded slanting ribs. The anterior channel is short. Length 45 mm., width 18 mm. This form seems to be related to *C. tupis* De Greg. or *C. monilifera* Lea of the Alabama Eocene, but the Barbados shell is considerably larger.

Pleurotoma (*Coronia*) sp. (Pl. XXIII, Fig. 32.)

Broken specimens from Spa with a short conical spire, concave platformed whorls and a rounded and weakly noded keel seem to come near to *C. childreni* De Greg. (pl. i, figs. 73 and 74), but the Barbados shells appear to belong to one or more species of much larger size.

Pleurotoma (*Bathytoma*) sp. (Pl. XXIV, Fig. 7.)

A specimen from Spa, 27 mm. long and 11 mm. wide, has the general ornamentation of *B. turbida* Sol. (*Iconogr.*, pl. l, fig. 221–2) of the Bartonian, but the Barbados form is larger.

Pleurotoma (*Eopleurotoma*) cf. *bicatena* Lam. (Pl. XXIV, Fig. 24.)

Three examples from Spa, one of them 22 mm. long and 6 mm. wide, resemble this form of the Lutetian (*Iconogr.*, pl. li, fig. 224–25) and also *E. francisci* de Rainc., of the Bartonian of Le Guepelle (*Iconogr.*, pl. li, fig. 224-24) The Barbados shell, however, seems more slender, and the sutures deeper and the early nodes more rounded.

Pleurotoma (*Strombina* ?) sp. (Pl. XXIV, Fig. 21.)

This specimen from Spa appears to come near to *Strombina gemmata* Conr., a reproduction of whose figure is given by De Gregorio (pl. i, fig. 84). It may, however, be a new species.

Cryptoconus sp. (Pl. XXIV, Fig. 23.)

Several smooth or nearly smooth forms occur at Spa. A slender fusiform species is 16 mm. long and 6 mm. wide, and resembles *C. evulsus* Desh. of the Cuisian (*Iconogr.*, pl. xlix, fig. 216–7) but in the Barbados shell the apertural sinus seems wider and shallower. Another rather large and stout species with the spire missing, 20 mm. long and 10 mm. wide, is more like *C. denudatus* Desh. of the Lutetian (*Iconogr.*, pl. xlix, fig. 216–10).

Cryptoconus barbadensis sp. nov. (Pl. XXIV, Fig. 6.)

Shell of eight whorls, rather solid, spire produced, sutures well impressed, whorls gently rounded, rather tabulate below the suture. Body whorl rather longer than the spire, narrowing rapidly anteriorly. Length 24 mm., width 11 mm. This species has rather the shape of *C. approximatus* Desh. of the Lutetian (*Iconogr.*, pl. xlix, fig. 216–9) but is stouter and has more tabulate whorls. Spa, five specimens.

Borsonia sp. (Pl. XXIV, Fig. 32.)

Specimens from Spa resemble *B. brevicula* Desh. of the Lutetian and Bartonian or *B. minor* Desh. of the Lutetian (*Iconogr.*, pl. xlix, fig. 218), but seem to be considerably larger.

Solarium sp. (Pl. XXIV, Figs. 38*a* and *b*.)

This small narrowly umbilicated form from Spa comes very near *S. bonneti* Cossm. from the Bartonian. (*Iconogr.*, pl. xvi, fig. 104–21.)

Serpulorbis sp. (Pl. XXIV, Fig. 31.)

Irregular masses and detached fragments of the tube resemble *S. ornatus* Lea. (De Greg., pl. x, figs. 34–38.)

Dentalium sp. (Pl. XXIV, Fig. 30.)

Shell rather thick, with numerous faint longitudinal rounded ribs crossed by faint growth interruptions giving under a lens a reticulate pattern. This form, common at Spa and Chalky Mount, has the shape of *D.* (*Entaliopsis*) *grande* Desh. of the Bartonian.

Ostrea cf. *sellaeformis* Conr. (Pl. XXIII, Fig. 4.)

Two right valves about 19 mm. long, and a fragment of a rather larger one agree with figures of this Alabama shell, especially De Gregorio, pl. xviii, figs. 21 and 22, and pl. xix, fig. 13, var. *divaricata* Lea. They also resemble some varieties of *O. flabellula* Lam. of the English Eocene, a form that De Gregorio quotes as a mutation of *O. sellaeformis*.

Ostrea sp. (Pl. XXIII, Fig. 3.)

Many specimens of a curious oyster occurred at Spa and elsewhere, all are isolated and often rolled left valves, and it is uncertain to which right valves they belong. Old shells are thick and swollen towards the umbo, and of irregular growth with strong growth ridges. The margin is beset with closely set acute radical incisions which tend to encroach upon the surface towards the umbo and in some specimens are filled with white shelly material. The largest example is 35 mm. long and 24 mm. wide.

They are rather like the early stage of examples of *O. marginidentata* S. V. Wood from Bracklesham in the British Museum, but in the Barbados form the marginal dentation is more pronounced. R. B. Newton illustrates *O.* cf. *marginidentata* from Nigeria (pl. vi, figs. 2–5) some of them rather like this shell. The wide hinge and ligament area suggests a resemblance with the type of *O. alabamiensis* Lea as figured by De Gregorio (pl. xviii, figs. 1–4).

Ostrea alabamiensis var. *linguaecanis* Lea.

Specimens very like this (De Greg., pl. xviii, figs. 9 and 10) occur at Spa.

Ostrea cf. *fraasi* Mayer-Eymar. (Pl. XXII, Fig. 12.)

A rather rolled right valve of a strongly incurved and arched costate *Ostrea* 40 mm. long and 27 mm. wide occurred at Spa. It resembles some Egyptian varieties of this species found near the Pyramids, but in the Barbados shell the growth interruptions towards the margin are less pronounced. It bears comparison also with specimens of *O. elegans* Desh. var. *exogyroides* May.-Eym. from Egypt.

Ostrea cf. *clot beyi* Bellardi. (Pl. XXIII, Fig. 5.)

A small specimen 18 mm. long and a fragment of another that must have been about 35 mm. wide from Spa appear identical with examples of this species that I collected in Egypt last year. It characterizes the higher part of the Mokattam Series near the Pyramids and elsewhere.

Plicatula polymorpha Bellardi. (Pl. XXIV, Fig. 22.)

One valve from Spa, 17 mm. long and 14 mm. wide, is very like specimens figured by R. B. Newton from the Nigerian Eocene (*Geol. Surv. Bull.*, pl. vi, figs. 6–9). Newton gives a bibliography and discussion of this species which occurs in the Upper Mokattam beds of Egypt and the Priabonian of Italy.

Arca (*Barbatia ?*) sp. (Pl. XXIV, Fig. 43.)

A left valve from Sunbeam, 14 mm. long and 9 mm. high, resembles in shape *A. laudunensis* Desh. from the Cuisian (*Iconogr.*, pl. xxxv, fig. 110–3), but is larger.

Arca sp. (Pl. XXIV, Fig. 42.)

This small *Arca* from Spa is very like figures of *Arca* (*Arcamalocardia*) *missipiensis* Conr. in De Gregorio (pl. xxiv, figs. 23–27).

Leda sp. (Pl. XXIII, Fig. 35.)

A *Leda* which must have attained an unusually large size occurs at Spa and Chalky Mount, but always broken, so that a specific diagnosis cannot be given. It seems to come very near to, though larger than, *L. claibornensis* Conr. (De Greg., pl. xxii, figs. 32 and 33, 35 and 36). The Barbados shell attained a length of 40–45 mm., and the beak is less posteriorly directed than in the Alabama species.

Petunculus sp. (Pl. XXIV, Fig. 37.)

A small sub-circular shell from Spa may be identical with *P. minor* Lea or *P. deltoideus* Lea of the Claiborne beds. Its surface is smooth with one growth interruption.

Nucula sp. (Pl. XXIII, Fig. 7.)

Shell with several more or less strong growth interruptions. It compares with *N. magnifica* Lea (De Greg., pl. xxii, fig. 19), but the beaks of the Barbados shell are more median. From Spa.

Nucula sp. (Pl. XXIII, Fig. 9.)

Outline sub-ovoid, beaks small, valves rather flat, surface smooth. Not unlike *N. bisulcata* Sow. of the Bartonian, but the beak is smaller in the Barbados shell. From Spa.

Nucula sp. (Pl. XXIII, Fig. 8.)

Beaks prominent, inflated, surface with very fine close-set growth foliations. It has a more median and prominent beak than *N. mixta* Desh. of the Lutetian and Bartonian. From Spa.

Venericardia cf. *planicosta* Lam.

A small portion of the apical part of a right valve looks very like a fragment of this well-known species. From Spa.

Cyrena spp. (Pl. XXII, Fig. 14.)

Cyrena-like shells of large and small size are common in bed "*a*" at Turner's Hall and below Spa, but the rock is so refractory that the hinge apparatus is almost invisible. A large form is 105 mm. long and 85 mm. high and 48 mm. thick, but larger ones still occur. The outline is well rounded, the beaks nearly median, and the growth lines coarse and foliaceous.

Another specimen (Fig. 14) is 56 mm. long, 42 mm. high, and 26 mm. thick. The beaks are slightly anterior and the ligament very long (26 mm.) and strong. Growth lines are regular and the valves seem to be slightly displaced as in the living *Cyrena*.

Cyrenoida (?) sp. (Pl. XXII, Fig. 13.)

Outline nearly circular, beaks low, nearly median, growth lines prominent and very regular. Length 40 mm., height 36 mm., thickness 17 mm. This specimen seems to have feeble hinge teeth and a small ligament, and the general regularity of outline suggests this genus. The living *C. dupontia* Johannis from Senegal, however, has a more inflated shell. This and other small *Cyrenoida*-like shells occur in bed " *a* " at Turner's Hall and below Spa.

Margaritana spp. (Pl. XXII, Fig. 15.)

Unio-like shells that occur in the sandstone bed " *a* " below Spa seem to belong to this genus. One of them is about 90 mm. long and 38 mm. high, but many of them are larger. The umbones are eroded and the ligament is large and prominent, and in shape they are not unlike the British *M. margaritifera* Linn. A large and thick water-rolled fragment of the beak and anterior part of a similar shell that must have been 150 mm. long occurred in the marine conglomerate at Spa, while other irregular shell fragments found there seem to have belonged to some species resembling in shape *U. humei* Newton or *U. crosthwaitei* Newton from the Nubian sandstone of Egypt.[1]

Mycetopus (?) sp.

Fragments of a rather large thin shell shaped like this genus were collected from the sandstone bed " *a* " below Spa.

Axinus scotlandicus sp. nov. (Pl. XXIII, Fig. 6.)

Shell thin, inflated, rather produced downwardly, beaks small, inrolled. There is a more or less deep and wide groove parallel to the hinder margin. The surface is ornamented with fine non-foliaceous growth lines. Length 16 mm., width 13 mm., thickness of valves 11 mm. It is common at Spa and Sunbeam. This form resembles *A. brongniarti* Desh. of the Cuisian (*Iconogr.*, pl. xxiii, fig. 81–2), but the Barbados shell is more elongated. Similar but smaller forms such as *Lucina papyracea* Lea occur in the Claiborne beds of Alabama.

Diplodonta (?) sp. (Pl. XXIII, Fig. 33.)

The teeth of this Astarte-like shell from Spa cannot be seen, but the outline resembles that of *Diplodonta* (or *Astarte*) *ungulina* Conr. (De Greg., pl. xxix, fig. 22). The young shell is nearly smooth, but towards the margin it has many concentric rounded growth ridges. The posterior margin is nearly straight, and the beak small with a long shallow lunule.

Diplodonta sp. (Pl. XXIII, Fig. 34.)

One specimen from Spa is rather like *D.* (*Felaniella*) *bidens* Desh. of the Lutetian and Bartonian. (*Iconogr.*, pl. xxiii, fig. 80–19.)

Tellina sp. (Pl. XXIII, Fig. 1.)

A valve from Spa rather resembles *T.* (*Macaliopsis*) *fayellensis* Cossm. (*Icongr.*, pl. vi, fig. 35–31) of the Bartonian, but the Barbados shell is nearly as high as it is wide.

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[1] Geol. Mag., Dec. V, Vol. VI, No. IX, Sept., 1909, p. 388, Pl. XX.

Mactra sp. (Pl. XXIV, Fig. 44.)

A small species of sub-triangular outline from Spa rather resembles *M. parilis* Conr. (De Greg., pl. xxxvi, figs. 8 and 9). From Spa.

Dosinia sp. (Pl. XXIII, Fig. 2.)

Fragments of a large *Dosinia* which must have been about 90 mm. in diameter occur at Spa. There is a concave well-sunken almost semicircular lunule, and the surface is smooth except for faint rather irregular growth lines, which increase in strength near the margin.

EXPLANATION OF PLATES XXI–XXIV.

Plate XXI.

Fig. 1.—View from Chalky Mount, Barbados, looking north-west. In the foreground are the soft shales and sandstones of the Scotland beds, above them is a thick white sandstone forming the summit of the hill. In the middle distance various beds of the Scotland district occur. On the skyline are the escarpment and terraces of the Coral Rock with Oceanics below ending near the sea in a point called Pico Teneriffe.

Fig. 2.—Part of Chalky Mount. To the left are the thick white sandstones that form the summit; to the right of these in the depression the fossiliferous conglomerate band passes up the slope and crops out among the bushes; farther to the right a thick series of steeply dipping variegated unfossiliferous shales and sandstones is seen.

Fig. 3.—View from Ragged Point in the south-east corner of Barbados looking north-west. The camera is standing on sandstones and grits at Ragged Point lighthouse low in the Scotland Series, covered by a thin layer of Coral Rock. Terraces of Coral Rock are seen rising in escarpments to the skyline. The sea cliffs in the middle distance are formed of Coral Rock with Scotland beds underlying it here and there.

Plate XXII.

Fig.
1.—*Surcula ingens* Mayer-Eymar. From Spa.
2.—*Mitra scotlandica* sp. nov. Spa.
3.—*Voluta* cf. *pyruloides* Conr. Spa.
4.—*Clavilithes* sp. Spa.
5.—*Rhopalithes* cf. *africanus* Newton. Spa.
6.—*Clavilithes* sp. Spa.
7.—*Clavilithes* sp. From Sunbeam.
8.—*Clavilithes solanderi* Grabau var. *barbadensis* nov. Spa.
9.—*Pleurotoma* (*Clavatula*) cf. *tupis* De Greg. Spa.
10.—*Surcula barbadensis* sp. nov. Spa.
11.—*Surcula barbadensis* var. *spirata* nov. Spa.
12.—*Ostrea* cf. *Fraasi* Mayer-Eymar. Spa.
13.—*Cyrenoida* (?) sp. Three-quarters nat. size. Bed "*a*", below Spa.
14.—*Cyrena* sp. Three-quarters nat. size. Bed "*a*", Turner's Hall.
15.—*Margaritana* sp. Three-quarters nat. size. Bed "*a*", below Spa.
16.—*Ampullaria* sp. One-half nat. size. Bed "*a*", Turner's Hall.

Plate XXIII.

1.—*Tellina* (*Macaliopsis*) sp. From Spa.
2.—*Dosinia* sp. Spa.
3.—*Ostrea* sp. (near *O. marginidentata*). Spa.
4.—*Ostrea* cf. *sellaeformis* Conr. Spa.
5.—*Ostrea* cf. *Clot beyi* Bellardi. Spa.
6.—*Axinus scotlandicus* sp. nov. Spa.

FIG.
7.—*Nucula* sp. (near *N. magnifica* Lea). Spa.
8.—*Nucula* sp. (near *N. mixta* Desh.). Spa.
9.—*Nucula* sp. (near *N. bisulcata* Sow.). Spa.
10.—*Cypraea* (*Bernayia*) cf. *inflata* Lam. Spa.
11.—*Ampullaria* (*Euspira* ?) sp. Spa.
12.—*Natica* (*Lunatia*) cf. *semilunata* De Greg. Spa.
13.—*Natica* (*Neverita*) cf. *mamma* Lea. Spa.
14.—Ditto, another specimen, showing umbilicus. Spa.
15.—Ditto, another specimen, umbilicus less calloused. Spa.
16.—*Cypraea* sp. Fragmentary specimen. Spa.
17.—*Siphonalia* sp. From Sunbeam.
18.—Ditto. Another specimen with more conspicuous striae. Sunbeam.
19.—*Ancilla* cf. *scamba* Conr. Spa.
20.—*Sigaretus* (*Sinum*) cf. *clathratum* Gmelin. Spa.
21.—*Nasseburna* cf. *calli* Aldrich. Spa.
22.—*Siphonalia* (*Pseudoneptunea*) sp. Spa.
23.—*Parvisipho* (?) sp. Spa.
24.—*Terebralia* sp. Spa.
25.—*Rostellaria* (?) sp. Spa.
26.—*Mesalia* sp. Spa.
27.—*Turritella* cf. *hybrida* Desh. Spa.
28.—*Turritella* cf. *interposita* Desh. Spa.
29.—Ditto, another variety. Spa.
30.—Ditto, another variety. Spa.
31.—*Pleurotoma* sp. Spa.
32.—*Pleurotoma* (*Coronia*) sp. Spa.
33.—*Diplodonta* (?) sp. Spa.
34.—*Diplodonta* sp. Spa.
35.—*Leda* (near *L. claibornensis* Conr). Spa.
36.—*Thersitea barbadensis* sp. nov. Spa.
37.—Ditto. Apical view of a rolled fragment. Spa.
38.—Ditto. A specimen with the spire completely calloused. Spa.
39.—Ditto. A specimen with the spire free. Spa.

PLATE XXIV.

1 *a, b.*—*Pseudoliva scotlandica* sp. nov. Spa.
2.—*Bayania* sp. Spa.
3.—*Lithasia* (?) sp. Spa.
4.—*Voluta* cf. *petrosa* Conr. var. *gracilis* Lea. From Sunbeam.
5.—*Tympanotonus* sp. Spa.
6.—*Cryptoconus barbadensis* sp. nov. Spa.
7.—*Pleurotoma* (*Bathytoma*) sp. Spa.
8.—*Mitra* sp. Spa.
9.—*Potamides* (?). Spa.
10.—*Terebralia* sp. Spa.
11.—*Bayania* sp. Spa.
12.—*Melanatria* sp. Spa.
13.—*Nerita tricarinata* Lam. Spa.
14.—Ditto. Another specimen. Spa.
15.—*Nassa* sp. Spa.
16.—*Cerithium* (*Tiaracerithium*) sp. Spa.
17.—*Pleurotoma* (*Clavatula*) cf. *desmia* Edw. Spa.
18 *a, b.*—*Oniscia scotlandica* sp. nov. Spa.
19.—*Ficula* (?) *scotlandica* sp. nov. Spa.
20.—*Siphonalia* (?) sp. Spa.
21.—*Pleurotoma* (*Strombina* ?) sp. Spa.
22.—*Plicatula polymorpha* Bellardi. Spa.
23.—*Cryptoconus* sp. Spa.
24.—*Pleurotoma* (*Eopleurotoma*) cf. *bicatena* Lam. Spa.

Fig.
25.—*Melania* sp. Spa.
26.—*Cerithium* (*Vulgocerithium* ?) sp. Spa.
27.—Ditto. Another specimen. Spa.
28.—*Olivella* cf. *micans* Desh. Spa.
29.—*Olivella* cf. *mitreola* Lam. Spa.
30.—*Dentalium* (*Entaliopsis*) cf. *grande* Desh. Spa.
31.—*Serpulorbis* sp. Spa.
32.—*Borsonia* sp. Spa.
33.—*Terebralia* sp. Spa.
34.—*Turbo* (*Pareuchelus* ?) sp. Spa.
35.—*Pleurotoma* sp. Spa.
36.—*Ancilla* sp. Sunbeam.
37.—*Pectunculus* sp. Spa.
38 *a, b*.—*Solarium* cf. *bonneti* Cossm. Spa.
39.—*Ancilla* (*Sparella*) sp. Spa.
40.—*Ancilla* (*Sparella*) sp. Spa.
41.—*Ancilla* (*Sparella*) cf. *dubia* Desh. Spa.
42.—*Arca* cf. *missipiensis* Conr. Spa.
43.—*Arca* (*Barbatia* ?) sp. Sunbeam.
44.—*Mactra* sp. Spa.
45.—*Cancellaria* cf. *stantoni* Dickerson. Spa.
46.—Ditto. Another specimen. Spa.
47.—*Stylocaenia* (?) sp. Spa.
48.—*Eupsammia* sp. Spa.
49.—Tooth of *Odontaspis* sp. Spa.

Radioactivity and the Earth's Thermal History. Part IV: A Criticism of Parts I, II and III.

By Arthur Holmes, D.Sc., A.R.C.S., F.G.S., The University, Durham.

TEN years ago I published two papers in this Magazine under the above title.[1] They constituted a first attempt to attack the new problems suggested by the universal presence of the radioactive elements in rocks, the discovery of which by the present Lord Rayleigh made it immediately necessary to abandon Kelvin's classical theory of the cooling of the earth. In 1913 I had already pointed out the possibility that Kelvin's problem might profitably be reversed, and that instead of calculating the age of the earth from its thermal condition, the latter, that is to say the distribution of temperature in depth, might be deduced from the earth's age.[2] Two years later the new problems were brought to a tentative solution on the general assumption that the earth had cooled down from a molten state, an assumption which, although traditional, was at that time less clearly justified than it is to-day. As a working hypothesis it was further assumed that the total amount of the radioactive elements in the earth was limited by the condition that the earth had in fact cooled down and was not, as seemed to be a possibility, growing hotter. Taking the age of the earth as

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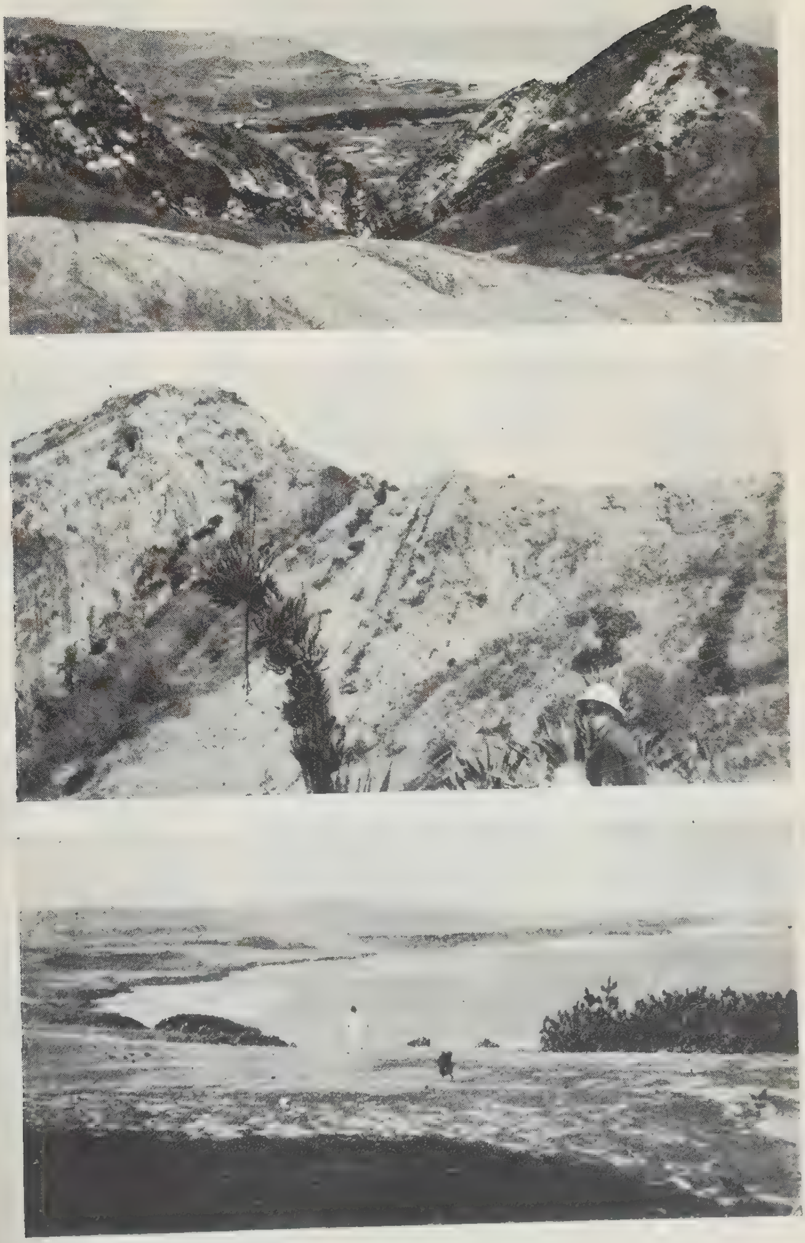
[1] Geol. Mag., 1915, Pt. I, p. 60, and Pt. II, p. 102.
[2] *The Age of the Earth*, 1913, p. 135.

PLATE XXI.

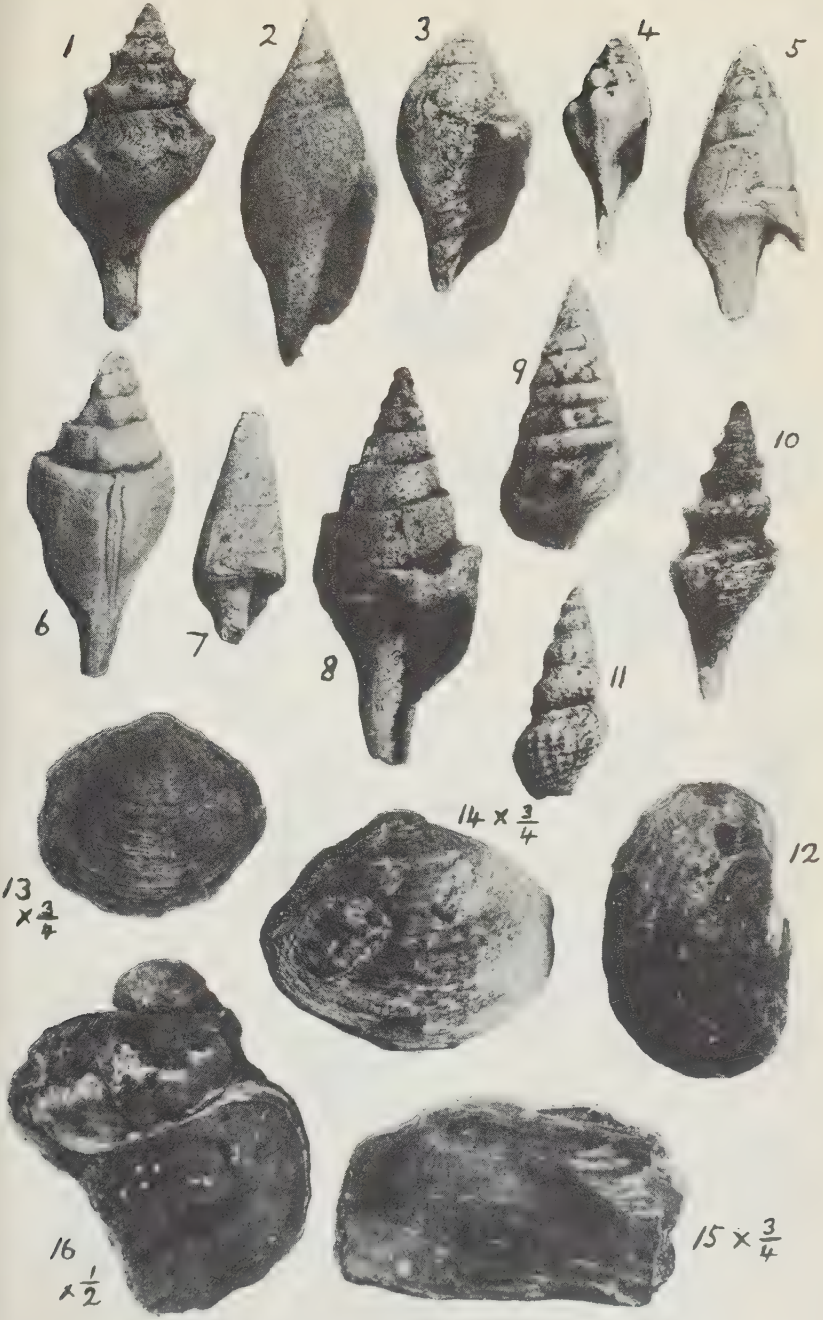


C. T. T., photo.

VIEWS OF BARBADOS.

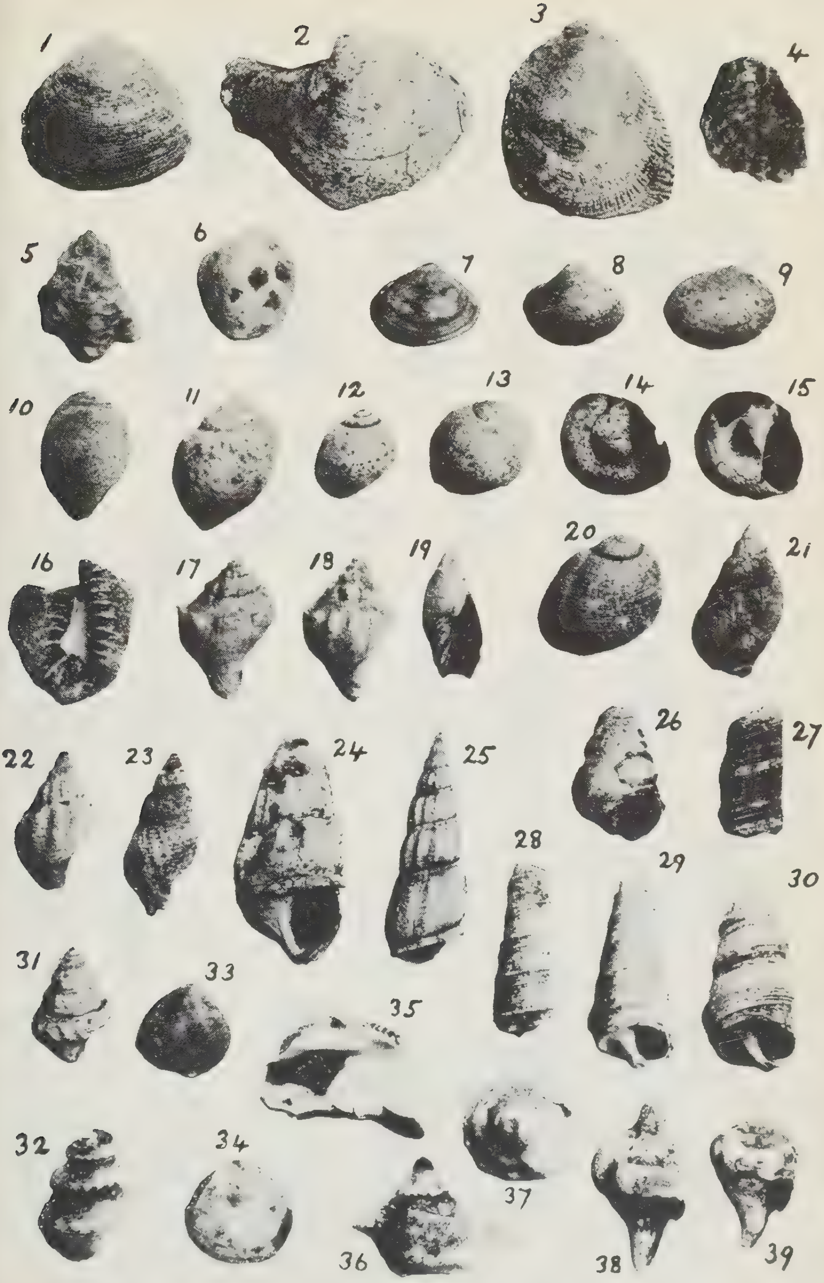
[To face p. 504.

PLATE XXII.



C. T. T., photo.

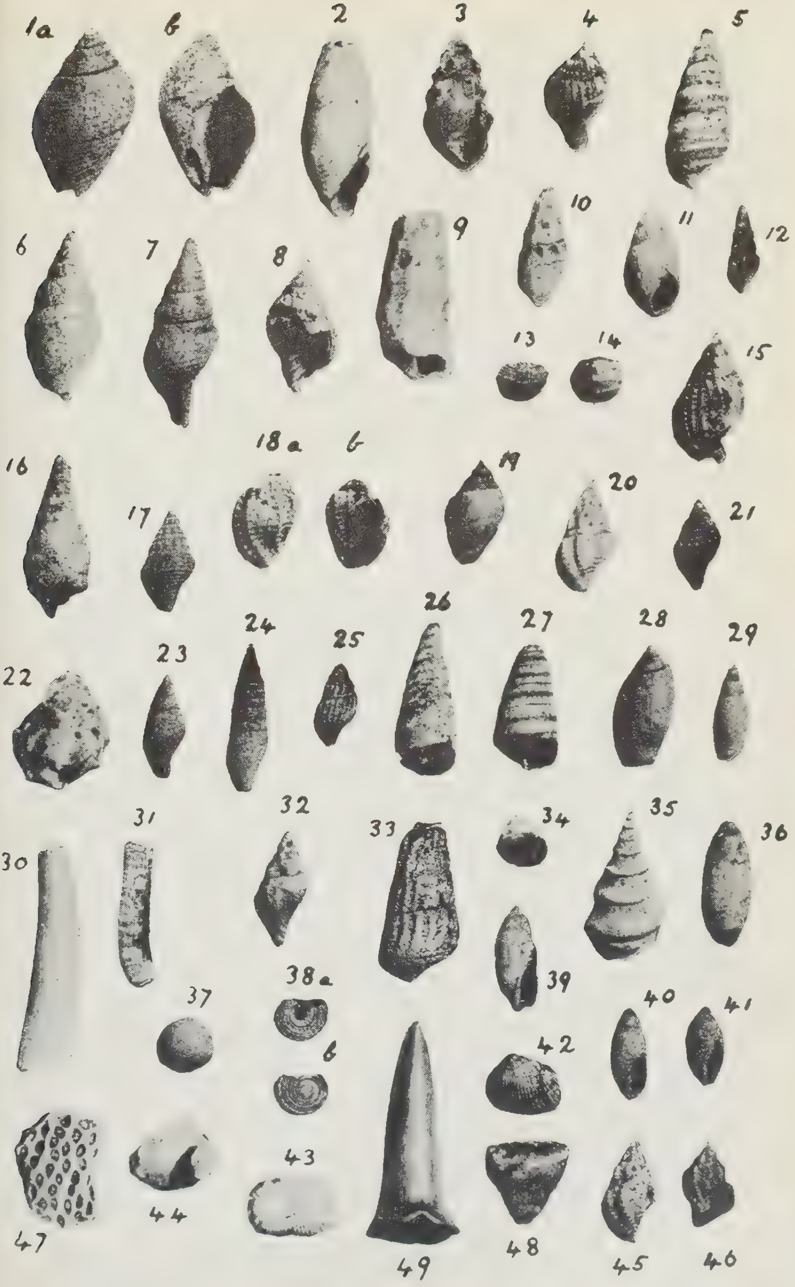
SCOTLAND FOSSILS, BARBADOS.



C. T. T., photo.

SCOTLAND FOSSILS, BARBADOS.

PLATE XXIV.



C. T. T., photo.

SCOTLAND FOSSILS, BARBADOS.

1,600 million years, this interval being adopted as the period of cooling since consolidation began, it was shown that the energy due to radioactive disintegration now supplies about three-quarters of the earth's total loss of heat by conduction to the surface and radiation into space. The total amount of the radioactive elements in the earth was thus directly calculable. The next step was to determine roughly the distribution of the radioactive elements in depth. The average proportions of uranium and thorium in the surface rocks being known, it was easy to show that unless these proportions decreased in depth it would be impossible for magmatic or volcanic temperatures to be attained within a reasonable distance of the surface. The falling off in depth deduced from the necessity of making allowance for igneous phenomena was then shown to correspond with the most probable succession of rock types in depth, since basaltic or gabbroid rocks contain about a third as much uranium and thorium as granites, and ultrabasic rocks a sixth or less. For mathematical treatment the downward decrease of radioactivity and heat generation was assumed to follow an exponential law. Finally the average distribution of temperature in the continental lithosphere was calculated with the results shown graphically in Fig. 1.

In a third paper,[1] continuing the series, I tested the downward distribution of temperature by its geophysical implications and showed that, like the lines of investigation followed by Barrell,[2] it led to the conception of an asthenosphere lying below the level of isostatic compensation. At that time I hoped to carry the investigation still further by calculating the level of no strain and discussing the possibilities of mountain building by compression, and igneous activity in general. Fortunately, Dr. Harold Jeffreys had become interested in the work at this stage, and late in 1916 he published an important paper dealing with the compression of the earth's crust in cooling.[3] His results definitely rejuvenated the thermal contraction theory of mountain building. Whereas on the Kelvin theory of cooling the level of no strain was not far below the present surface and the amount of contraction available was woefully inadequate, the new theory gave the level of no strain at over 100 kms. below the surface, and a total amount of compression of apparently the same order of magnitude as that actually implied in the crumpled and overthrust formations of existing mountain ranges. Nevertheless, the localized distribution of the crustal shortening, as in the Alps and the Appalachians, still presented serious mechanical difficulties. The shortening achieved during pre-Hercynian periods of mountain building remained to be explained. Moreover, the estimates of contraction in such systems as the Alps (200-300 kms.), the Appalachians (300 kms.), and the Rockies (60 kms.), have recently been considerably increased. For these reasons geologists have rejected the new thermal contraction theory as being by itself still inadequate. My own opinion was that the theory explained about a third or a quarter of all the folding and overthrusting that has demonstrably occurred during the earth's known history.[1] However, the original radiothermal theory of the earth's heat could not be held to stand or fall by its success or failure in explaining tectonic structures, for many other processes besides thermal contraction might conceivably have been involved.

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[1] Geol. Mag., 1916, Pt. III, p. 265.
[2] *Journ. Geol.*, vol. xxiii, 1915, p. 44.
[3] *Phil. Mag.*, vol. xxxii, Dec., 1916, p. 575.

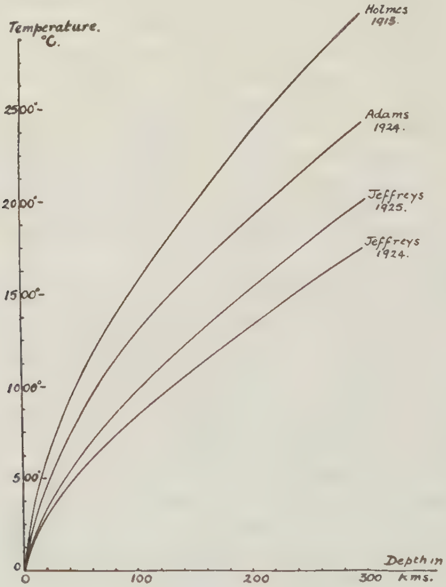

Fig. 1.—Temperature-depth curves based on a cooling earth 1,600 million years old with radioactivity decreasing downwards exponentially.

With regard to igneous activity, the theory has been much less happy. The suggestions first made [2] have not been further developed for the sufficient reason that few of the possible deductions from them could be matched with the observed facts. Where the amount of radioactive matter in any column of the crust is greater than the continental average already arrived at the temperature will rise and favour the growth of magmas. Such excesses of heat are particularly likely to accumulate beneath geosynclines after thick masses of sediments have been deposited; and also in the depths above which compressed mountain ranges have arisen.

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[1] Geol. Mag., 1917, p. 88.

[2] Geol. Mag., 1916, p. 272.

So far there is a broad, though misleadingly simple correspondence with the associations of contemporaneous lava flows and batholithic intrusions. But where, instead of sedimentation, denudation has been long-continued; where the stresses have been tensional rather than compressional; and where epirogenic movements have been in control; the genesis of magmas by superheating due to radiothermal energy clearly cannot be invoked on the theory under discussion. Yet plateau lavas and associated types of igneous activity have broken out with the utmost vigour in just such regions as appear to be the most improbable. There can be no doubt that here the theory breaks down completely, and the object of this paper is to recognize the fact. In Part V the nature of the modifications that it is necessary to introduce will be discussed.

DATA FROM WHICH THE CURVES WERE CONSTRUCTED.

Data Employed.	*Holmes,* 1915.	*Jeffreys,* 1924.	*Jeffreys,* 1925.	*Adams,* 1924.
The initial temperature at which consolidation began near the surface	1000° C.	1200° C.	1400° C.	1400° C.
The initial temperature gradient . . .	5° C.	2·5° C.	3° C.	4° C. per km.
The present temp. gradient :—				
(*a*) salic rocks .	32° C.	——		35° C. per km.
(*b*) femic rocks .	48° C.	——		45° C. per km.
Value adopted .	38° C.	32° C. per km.		*
Specific heat of rocks .	0·25	0·25		0·25 cals. per gr.
Density of rocks :—				
(*a*) salic rocks .	2·66	——		2·80
(*b*) femic rocks .	2·94	——		3·30
Value adopted .	2·80	2·80		*
Thermal conductivity :—				
(*a*) salic rocks .	0·006	0·006		0·007 c.g.s.
(*b*) femic rocks .	0·004	0·004		0·0055 c.g.s.
Value adopted .	0·005	0·005 c.g.s.		*
Heat production due to radioactivity per c.c. of rock :—				
(*a*) salic rocks .	$10{\cdot}1 \times 10^{-13}$ cals. per sec.			
(*b*) femic rocks .	$2{\cdot}7 \times 10^{-13}$ cals. per sec.			
Value adopted .	$6{\cdot}4 \times 10^{-13}$	$10{\cdot}1 \times 10^{-13}$		$10{\cdot}1 \times 10^{-13}$
Depth in which heat production due to radioactivity decreases by half . . .	17 km	9 km.		14 km.
Period of cooling .	1600×10^{6}	1600×10^{6}		1600×10^{6} years

* Both values were used. Adams drew temperature curves for salic rocks near the surface and for femic rocks in depth. From these a final curve transitional from one to the other was constructed.

It is remarkable, in view of the outstanding difficulty to which attention has just been directed, that during the last ten years the theory should not have met with any unfavourable criticism. Dr. Harold Jeffreys has adopted it, with but slight revision of the data, in his recent book *The Earth*, and still more recently he writes:[1] "The quantity of observational data relevant to the earth's thermal state is very large, and the whole of it can be co-ordinated in a single hypothesis, due to Dr. A. Holmes . . . Any alternative hypothesis, such as supposing that the earth is getting hotter, immediately leads to inferences flatly disagreeing with observations."[2] In a recent paper on *Temperatures at Moderate Depths within the Earth*, Dr. L. H. Adams writes,[3] after referring to the fallacy on which the Kelvin theory of cooling was based: "It remained for Holmes to make the bold step which reconciles in a satisfactory manner all the factors involved. Instead of attempting to calculate the age of the earth, and thence the interior temperatures, from the surface gradient, he started with the age of the earth as determined by other means, and from that datum calculated the total amount of radioactive material in the earth and thence the present temperatures at various depths."

These authors have constructed temperature-depth curves which are somewhat different from mine, and to facilitate comparison their curves are plotted on Fig. 1. It will be seen that the first curve is by far the most favourable to vulcanism, whereas Jeffreys' 1924 curve is the least favourable. We both agree, however, that the intermediate curve due to Adams is the best yet put forward on the available data. That is to say, careful revision of the original work has been in the direction of indicating lower temperatures in depth, and as the original estimates are in my opinion inadequate to meet the requirements of igneous processes, it follows that the difficulties to be faced are even more serious than they appeared to be at first. Although I am therefore unable to agree that my former work co-ordinates the whole of the data, or reconciles in a satisfactory manner all the factors involved, I hope so to reconstruct it that it shall more closely justify these claims.

It is first of all necessary to demonstrate that the distribution of radioactivity in depth hitherto adopted must be considerably modified. A preliminary examination of any of the curves of Fig. 1 indicates at once that a temperature at which basaltic magma could form cannot be attained within 100 km. of the surface. Taking the curve drawn by Adams as the best, the temperature at 100 km. is 1,300° C., of which only 900° C. is available for comparison with the temperature at which basaltic magma can exist at the surface. This is because the fusion point is raised by pressure, the particular rate on which the curve is based being 4° C. per km. Thus if basaltic magma could exist at 900° C. under surface conditions, a possibility not in itself to be denied, it would require 1,300° C. to come into existence at a depth of 100 km. If then the pressure at that depth were to be relieved by surface denudation, internal tension, or deep faulting, it is conceivable that the temperature might be sufficient to permit fusion. However, we need not proceed to consider the mechanical difficulties involved, for a simple deduction shows that basaltic magma could not come directly from such a depth. On the theory under discussion the amount of radium in the material 100 km. below sea-level would be less than $0{\cdot}1 \times 10^{-12}$ grams per gram of rock. The average amount of radium in actual basalts is more than ten times this amount, and for no known region is it less than five times. This fact is clearly brought out by the determinations compiled in the adjoining table :—

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[1] *Am. Journ. Sci.*, vol. xi, 1925, pp. 403-4.

[2] See also *Nature*, 6th June, 1925, p. 876.

[3] *Journ. Wash. Acad. Sci.*, vol. xiv, 1924, p. 461.

RADIUM CONTENT OF BASALTIC AND GRANITIC ROCKS.

Region.	*Basaltic Rocks.*		*Granites.*		*Analyst and Reference.*
	No.	*Average Ra.*	*No.*	*Average Ra.*	
Brito-Arctic .	7	0·50	—	—	Strutt 1 & 2
Hebridean .	11	0·50	—	—	Joly 3
,, .	6	0·77	4	1·48	Joly 4
Scotland . .	—	—	7	1·71	Joly 4
Cornwall . .	—	—	4	3·55	Strutt 1
Shap . .	—	—	1	3·31	Strutt 1
Leinster . .	—	—	23	1·68	Fletcher 5
,, .	—	—	5	1·80	Joly 6
European .	15	1·30	—	—	Joly 4
Aar Massif .	—	—	9	6·00	Joly 7
Finland . .	—	—	15	4·39	Joly 4
Deccan . .	6	0·77	—	—	Joly 4
Mysore . .	—	—	10	1·02	Smeeth and Watson 8
,, . .	—	—	5	1·37	
Karroo, S.A. .	4	1·44	—	—	Joly 4
South Africa .	—	—	4	2.27	Holmes 9
Mozambique .	8	0·90	23	2·33	Holmes 10 & 11
Western U.S.A.	7	1·69	—	—	Joly 4
Eastern U.S.A.	5	1·09	—	—	Joly 4
Antarctica .	4	0·89	4	0·55	Fletcher 12
Antarctic Is. .	6	0 54	2	1·76	Farr & Florance 13
Pacific Is. .	4	1·09	—	—	Joly 4
Indian Oc. Is. .	3	0·86	—	—	Joly 4
Atlantic Is. .	8	1·31	—	—	Joly 4
World . .	18	1·40	62	2·70	Joly 3

NOTE.—The figures for radium represent grams $\times 10^{-12}$ per gram of rock. "*No.*" means the number of specimens analysed.

1. R. J. Strutt, *Proc. Roy. Soc.*, A., 1906, p. 472.
2. R. J. Strutt, *Proc. Roy. Soc.*, A., 1911, p. 378.
3. J. Joly, *Phil. Mag.*, October, 1912, p. 697.
4. J. Joly, *Phil. Mag.*, vol. xlviii, November, 1924, p. 819.
5. A. L. Fletcher, *Phil. Mag.*, January, 1911, p. 106.
6. J. Joly, *Phil. Mag.*, July, 1911, p. 142.
7. J. Joly, *Phil. Mag.*, February, 1912, p. 209.
8. W. F. Smeeth and H. E. Watson, *Phil. Mag.*, February, 1918, p. 213.
9. A. Holmes, *The Age of the Earth*, 1913, pp. 182–3.
10. A. Holmes, *Q.J.G.S.*, vol. lxxii, 1917, p. 275.
11. A. Holmes, *Q.J.G.S.*, vol. lxxiv, 1918, pp. 59 and 64.
12. A. L. Fletcher, *Phil. Mag.*, June, 1911, p. 771.
13. C. C. Farr and D. C. H. Florance, *Phil. Mag.*, November, 1909, p. 814.

On the basis of these data, to which the chief determinations for granites have also been added, it is possible to ascertain approximately the limits of depth within which material of basaltic composition is likely to be in place. The ranges for the two contrasted types of rock overlap on each side of $1{\cdot}4 \times 10^{-12}$, and this figure may therefore be taken, for the purpose of the present argument, as the most probable value separating basaltic and granitic types of material. At the other end of the basalt range peridotite comes in with a well-established average of $0{\cdot}50 \times 10^{-12}$. In Fig. 2 a curve is drawn showing the distribution of radium in depth on which the temperature curve (here reproduced for comparison) depends. In determining the temperature thorium is quite as important as radium, but to avoid confusion the thorium curve is not drawn. It would be similar in form to that for radium, but would approach the base-line more rapidly. Rocks with the radium content proper to basaltic types should evidently be in place below 20 km. and above 45 km. The corresponding temperatures are 400° C. and 800° C. Even a total relief of pressure would still leave the rocks hundreds of degrees below any temperature at which they could be expected to fuse; and burial beneath, say, 10 km. of sediments, themselves more radioactive than basalt, would be

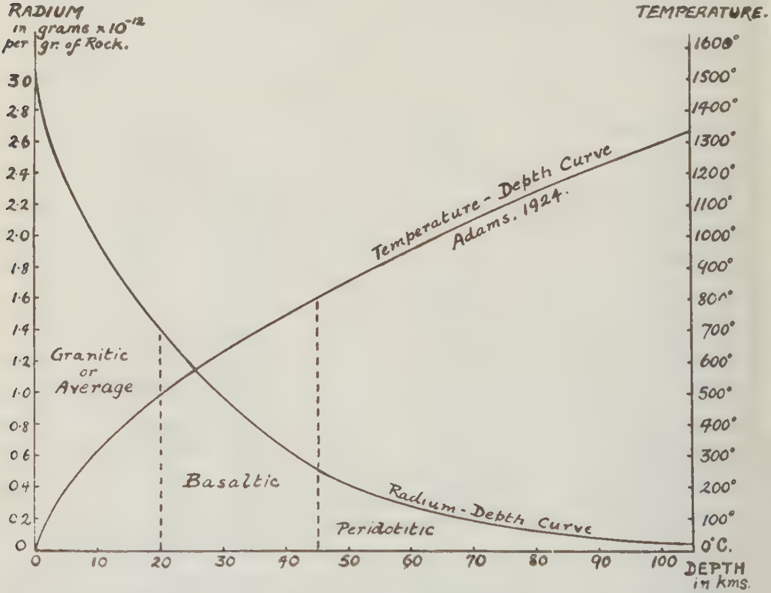

FIG. 2.—Curve showing the assumed downward distribution of radium with depth, and the temperature-depth curve of Adams. The corresponding downward distribution of chemical rock-types, as indicated by their observed radium-contents, is shown by the dotted lines.

still incompetent to raise the basal temperature to the degree necessary to promote fusion.

If the theory breaks down when tested in this way, its position is still worse when the rocks beneath the oceans are considered. The distribution of chemical rock types indicated by the radium curve of Fig. 2 is approximately as follows down to the level of isostatic compensation taken at a depth of 60 km.

Range of depth in kms.	*Average content of radium.*	*Type of rock indicated.*	*Approximate density.*[1]
– 0·7 to 20	$2{\cdot}2 \times 10^{-12}$ grs./gr.	Average.	2·8
20 to 45	$1{\cdot}05 \times 10^{-12}$ grs./gr.	Basaltic	3·0
45 to 60	$0{\cdot}4 \times 10^{-12}$ grs./gr.	Ultrabasic	3·4

The continental column is taken as rising to 0·7 km. above sea level, and the corresponding oceanic column is then about 56 km. thick with 4 km. of water above. On the principle of isostasy, and assuming the practical absence of "average" rocks beneath the ocean floor,[2] the thicknesses of the basaltic materials (x km.) and ultrabasic materials (y km.) are given by the following simple equations:—

$$3{\cdot}0x + 3{\cdot}4y + 4 = (20{\cdot}7 \times 2{\cdot}8) + (25 \times 3{\cdot}0) + (15 \times 3{\cdot}4) = 184.$$

$$x + y = 56.$$

Solving, we get $x = 26$ km.; and $y = 30$ km.

The temperature at the base of the basaltic layer underlying the ocean floor can now be calculated by the method of Part II,[3] using the data appropriate to "basic" rocks.[4] It comes out at 450° C. lower than the temperature at the base of the basaltic layer beneath the continents. Similarly, at a depth of 60 km. below sea-level, that is at Bowie's general level of isostatic compensation, the temperature in the oceanic column is found to be 350° C. lower than at the same level in the continental column.[5] Thus even if igneous activity could originate beneath the continents, it would still be far from possible beneath the oceans.

Obviously the temperature distribution deduced for the sub-oceanic rocks could not continue side by side with that for the sub-continental rocks. The figures have been calculated merely to reveal the extreme improbability of the conditions shown graphically in Figs. 1 and 2. In whatever way the range of possibilities arising from the radiothermal theory is explored, the conclusion is forced upon one that neither by relief of pressure nor by burial beneath a deep geosyncline filled with sediments would it be possible for igneous activity to originate at such a depth that basaltic magmas could form.

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[1] These estimates are near enough for the purpose of the discussion, and consequently the effects of temperature and compressibility need not be considered.

[2] Oceanic islands may represent foci of differentiation which, by producing columns of salic rock, have enabled them to stand high above the surrounding floor.

[3] GEOL. MAG., 1915, p. 111.

[4] Ibid., Table II, p. 66.

[5] Taking 96 km. as the depth of isostatic compensation would make no difference here, as the composition of the upper levels would not be affected. In the example considered the local level of compensation would be at a depth of 45 km., the rocks in both columns below this level being ultrabasic.

Ten years ago Barrell suggested that the asthenosphere (200 to 400 km. below the surface) should be regarded as the most likely region of magma genesis,[1] but he pictured the formation of a gas-saturated "liquid of an andesitic or basaltic nature" which would insinuate itself upwards to form magma-reservoirs in the higher levels of the crust. From the standpoint of the distribution of radium expressed in Fig. 2, Barrell's conception falls outside the possibilities open to discussion. Moreover, if material of such composition had ever existed in the asthenosphere it would have been fluid from the start on account of its depth and radioactive contents, and would therefore have been expelled long ago.

There still remains for consideration the accumulation of excess of heat beneath high plateaus and compressed mountain ranges. From the principle of isostasy it follows that these regions must be underlain by an abnormal thickness of the lighter rocks, and it is consequently to be expected that the downward distribution of radium will be appropriate to that of the rocks containing it. Applying the simple method adopted on page 511 for an area like Thibet, 4,500 metres above sea-level, we find 42·5 km. for the thickness of the layer averaging 2·8 in density, and 22 km. for that of the underlying basaltic layer having a density averaging 3·0. The equations are

$$2{\cdot}8\,w + 3{\cdot}0\,x = 184$$
$$\text{and} \quad w + x = 64{\cdot}5$$

where w is the thickness of the upper layer and x that of the basaltic layer down to the level of isostatic compensation. Without entering into very careful calculations, which would not be justified by the roughness of the test, it is nevertheless easy to arrive at the temperatures at depths of 42·5 km. and 64·5 km. from the surface of the plateau. Evidently the output of radiothermal energy now falls off from that characteristic of granite to that of basalt in 42·5 km. instead of in 20·7 km. Thus in the equation giving the temperature at any depth, $\theta = \frac{A}{a^2k}(1-c^{-ax})$, a is now about half the average value. Applying the method of Part II,[2] and using the data for average rock,[3] the temperatures at the two depths are of the order 1,300° C. and 1,700° C. respectively. Similarly for a region rising 6 km. above sea level the whole of the rocks down to the assumed level of isostatic compensation at 60 km. below sea-level are equivalent to a column averaging 2·8 in density. With this distribution a becomes one-third of the average value, and the temperature at the base of the column now rises to 2,800° C. It is therefore beyond all doubt that the original hypothesis is fully competent to give temperatures under high-standing mountain ranges sufficient to initiate batholithic intrusions and volcanoes of the Andes type. After the compression of the crustal materials, fusion should be increasingly facilitated, and consequently the theory explains why batholithic intrusions accompany and often closely follow orogenesis, and why in general they occupy the cores of the ranges in which they occur.

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[1] *Journ. Geol.*, vol. xxiii, 1915, pp. 438–9.

[2] Geol. Mag., 1915, p. 111.

[3] Ibid., Table II, p. 66.

So far the discussion indicates that away from high mountains there is no possibility of the formation of basaltic magma except by the introduction of more heat than is permitted by the theory as it stands. It may be argued that locally the rocks may be richer in the radioactive elements than the average materials hitherto considered in arriving at average estimates of temperature. This possibility may suggest an effective cause of fusion during the earth's earliest ages, but it can scarcely be invoked for Tertiary vulcanism. Reference to the table on page 509 shows at once that in Scotland and India the values for radium in both granites and basalts are actually well below the average figures adopted.

It must therefore be admitted that in such regions either the total amount of the radioactive elements must be greater than the maximum allowed by the original theory, or heat must have been introduced from the deep-seated peridotite that presumably underlies the basaltic layer. It has already been stated that the theory leads to the calculation of the level of no strain at a depth just below 100 km. Above this level the rocks are in a state of compression, while below it tension is developed, reaching a maximum at the level of most rapid cooling, about 500 km. below the surface. Now it is conceivable that fusion might be brought about by a state of stress in which a horizontal pull is combined with a vertical pressure. The thermodynamics of a system under such conditions are by no means easy to understand. The fusion point of the solid phase would undoubtedly be lowered by the stress difference and fusion would therefore be promoted. The resulting liquid phase, however, would not be influenced by the tension, but only by the hydrostatic pressure under which it found itself. This would be greater than before owing to expansion, and consequently, unless the liquid phase were free to be squeezed upwards, it would resolidify in a phase possibly more stable than that from which it was formed. The process is rather like that which permits recrystallization to take place during metamorphism under conditions of directed pressure, and it does not seem to be one that could lead to the growth of a permanent body of magma. It is perhaps just possible that the temporary increase of hydrostatic pressure in the fluid phase might be sufficient to allow it to insinuate itself upwards as a thin wedge until it reached a level where its superheat relative to that level would maintain it as a fluid independently of the overhead pressure. More probably the increase of pressure due to the first formation of liquid would localize a relief of tension in the materials above which might then flash into a wedge of fluid formed in place. In either case the thin threads of magma that might in this way approach the level of no strain would be minute in volume and too diffused in distribution to form extensive magma basins in any one place.

If the above argument is wrong, for in this matter I am open to correction, and a wedge of magma of significant size did reach the level of no strain, then it would either inject itself laterally or continue upwards by a process of overhead stoping. In no other way could the thick zone of compression be penetrated. On reaching the basaltic layer a great deal of the initial superheat would be already lost, and stoping would come to an end or would become very slow on account of the slight and probably inhibitive difference in density between solid basaltic material and fused ultrabasic material. If the former were a crystalline aggregate like eclogite then we might assume that stoping would continue, and that a small volume of basaltic magma would be formed from the blocks as they sank into the hotter depths.

It is to be noticed that the above quite imaginary process is not one that can add material to the zone of compression by subtracting it from the underlying zone of tension. Stoping provides a mechanism for transferring heat upwards by exchange of hot fluid for colder solid, but the total volume of the earth beneath the level of no strain is clearly not diminished. The original expansion of solid material to form a fluid magmatic wedge, if it could happen at all, would neutralize the very contraction that brought it into being. Relief of tension by the formation of fluid would prevent the radial thinning of the zone of tension which is appealed to as the cause of compression and mountain building in the zone above the level of no strain. In conclusion, it appears to me that the vague possibility that igneous activity may begin with the fusion of peridotite hundreds of kilometres below the surface, while it cannot be positively excluded, is one that raises so many difficulties at every stage that it cannot be reasonably invoked as a practical explanation of vulcanism. Moreover, if it is invoked, then the contraction theory of mountain building already developed becomes not only partly but hopelessly inadequate.

We are therefore left with only one known way out of the impasse: there must be more uranium and thorium in the deep-seated rocks than has hitherto been thought possible on the theory of a cooling earth. This conclusion was rejected ten years ago, and has since been rejected by other workers in the same field, partly because it was thought necessarily to imply that the earth must be getting hotter, and partly because the difficulties in the way of explaining vulcanism were not, and have not been, fully realized. However, since it is an obvious truism that a theory to be tenable must not contradict observational facts, we must give up the older theory and start afresh with different assumptions, guided as far as possible by such scanty data as are available and relevant. Unfortunately, once the straightforward conception of a continuously cooling earth is abandoned, the possibilities become hard to visualize, unwieldy in their complex interrelations, and difficult to check except by the most complete details of geological history, and of the physical properties of materials under unfamiliar conditions. Nevertheless an attempt must be made, and if mistakes are involved at first, then at least their recognition and correction in the future will mark a beginning of sound progress.

(*To be continued.*)

Seasonal Rhythm in the Tertiary Sediments of Burma.[1]

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I. Introduction.

At the Bournemouth meeting of the British Association in 1919, Dr. J. W. Evans, in his characteristically stimulating address to Section C, pleaded for the closer examination of sediments by geologists in the field. He instanced especially the presence of rhythmic banding on a small scale in sediments of widely varying ages as a phenomenon badly in need of further study. Engaged in field work on the oil-bearing Tertiary rocks of Burma, the writer has been struck by the repeated occurrence of rhythmic banding in those beds. The present note embodies the firstfruits of the detailed examination of the banding.

II. The Tertiary Geography and Geology of Burma.

In 1922 the writer gave a brief summary of the Tertiary Geology of Burma.[2] Before describing the detailed lithology of the Tertiary beds it will be desirable briefly to recapitulate the geology and to add a few details, bringing the 1922 account up to date.

In Tertiary times Burma was occupied by a long narrow gulf, bounded by the land mass of the Shan Plateau or Indo-Malayan Mountain System on the east and by a narrow strip of land (marked now by the crest of the Arakan Yomas) on the west. To the north lay a great land mass from which drained a succession of mighty rivers. Of these rivers at least one, which may be called the

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[1] Paper read before Section C of the British Association for the Advancement of Science, Southampton Meeting, 1925.

[2] Geol. Mag., Vol. LIX, 1922, pp. 481–501.

Proto-Irrawaddy, drained into the Burmese Gulf. Another, further west, drained into the Assamese Gulf, and, as Murray Stuart has pointed out, the sediments from the two may be continuous at least locally over the divide in northernmost Burma. The history of the Tertiary period in Burma may be described as the story of the infilling of the gulf by sediments from the north and the consequent retreat of marine conditions southwards. The history is complicated by intermittent earth-movements which caused a periodical deepening of the gulf-trough or a buckling of the floor and the temporary return of marine conditions northwards. The earth-movements have resulted also in the formation of the great fold-range of the Arakan Yomas.

The Tertiary sediments infilling the gulf are usually divided into three groups :—

Irrawaddian (Mio-Pliocene)
Peguan (Oligo-Miocene)
Eocene

The Eocene beds are exposed mainly down the western margin of the old gulf, but occur also in inliers more towards the centre of the gulf in the northern part. The Eocene sediments are as yet imperfectly described, but reach an enormous thickness—not less than 12,000 feet in measured sections.

The Peguan and Irrawaddian are to some extent complementary. The Irrawaddian is a fluvio-lacustrine series decreasing in importance and thickness southwards, i.e. towards the seaward end of the gulf. The higher part of the marine Peguan in the south is almost certainly contemporaneous with the lower part of the Irrawaddian further north. As it is with the marine Peguan that this paper is concerned, the series needs careful definition. For many years the Pegu Series has generally been understood to embrace the Post-Eocene (or " post-Nummilitic ") and pre-Irrawaddian rocks of Burma. This is the sense in which it was used by its author, W. Theobald, in 1870. From time to time, however, various minor adjustments have become necessary to reconcile discrepancies. For example, Dr. Cotter has shown that Theobald's base is vitiated through the fact that he has included *Lepidocyclina* beds in the Eocene in some cases (owing to confusion of small Lepidocyclines or Operculines with Nummulites) but not in others. Dr. Cotter has also alluded to the difficulty of drawing any boundary between the " Mogaung Sands " (included by Theobald in his Fossil-Wood Group or Irrawaddian) and the beds below. Some years ago it was suggested and to some extent adopted that the Pegu Series in the broad sense be separated into Shwezetaw Sandstones at the base, followed by the Padaung Clay and then by the Pegu Series (*sensu stricto*).[1] Again, but a few years ago Vredenburg provisionally defined the Pegu Series as corresponding " essentially with the

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[1] Cotter, *Rec. Geol. Surv. India*, vol. xli, 1912, p. 221 ; compare also Porro, ibid., vol. xlv, 1915, pp. 249–70 and pls. xxv–vi.

marine facies of the post-Eocene Tertiary in the eastern part of the Arakan Yoma, in the Pegu Yoma, and in the intervening Irrawaddy valley ".[1] In order to obviate any possible doubts as to the exact meaning of the " Pegu Series ", the writer has used the term Peguan to embrace the post-Eocene and pre-Irrawaddian rocks of Burma. The Peguan corresponds essentially with the Pegu Series, *sensu lato.* It ranges in age from lowest Oligocene up to and including the Burdigalian. It is entirely marine in the south (marine Peguan), but passes gradually northwards into continental types of deposit (continental Peguan). It is true that the lowest Irrawaddian of Upper Burma may be of the same age as the highest Peguan of Lower Burma, but no other mapable or even identifiable division can be suggested. The marine Peguan is almost everywhere divisible into three broad lithological groups which have no reference to time horizons :—

(iii) An upper mixed sandy and shaley group, including the Lower and Upper Prome Beds (with the Kama Clay) of Lower Burma ; the upper sandy or mixed groups of Thayetmyo and Minbu Districts and the exposed Pegu rocks of the oilfields of Yenangyaung, Singu, and Yenangyat (at least the higher beds).

(ii) A middle group of rubbly, non-sandy shales, the Sitsayan Shales of Lower Burma, decreasing in thickness northwards and passing into the Padaung Clays.

(i) A lower sandy or mixed group, comprising the Shwezetaw Sandstone of Upper Burma. This group becomes less marked southwards and eventually disappears.

At the base of the Peguan is found the Kyet-u-bôk bed which may either be regarded as the top of the Eocene or as the base of the Peguan.

Both the upper and lower groups of the Peguan become continental northwards—as in the Pakokku and Lower Chindwin Districts—whilst the Padaung Clay remains marine for the greatest distance—at least as far north as the northern part of the Pakokku District. Eventually the whole of the Peguan becomes continental.

In the 1922 summary, the writer noted that the marine Peguan had been divided by Vredenburg into six palaeontological stages :—

6. Akauktaung Stage.
5. Pyalo Stage.
4. Kama Stage.
3. Singu Stage.
2. Padaung or Sitsayan Stage.
1. Shwezetaw Stage.

Stages 1 to 4 were established on a sure foundation, being based on the well-known faunas of Yenangyat, Singu, Minbu, and Kama. The Pyalo Stage was founded on the presence of an oyster held by Vredenburg to be identical with *Ostrea latimarginata*, a characteristic fossil of the upper Gaj of India and therefore denoting the presence of a stage later than the Kama Stage and equivalent to the upper Gaj of India (Burdigalian).

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[1] Vredenburg, ibid., vol. li, 1921, p. 227.

In the cold season of 1922–3 the writer carried out a series of studies on the Peguan Rocks along the River Irrawaddy from Yenangyaung to Prome. Two of the main results of this study are :—

(1) To demonstrate the non-existence of a Pyalo Stage. The Geological Department of the Burmah Oil Co., Ltd., kindly supplied information as to the exact locality near Pyalo from which *Ostrea latimarginata* was found. The bed is situated in the stream immediately to the north-west of Sitsaba Village. Both above and below are other fossil beds which appear to yield typical Kama faunas. At numerous surrounding localities—Pyalo, Pyaye, Thanat and Kamagale typical Kama faunas have been found to extend right up to the base of the Irrawaddian, leaving no room for a Pyalo Stage. Further, no other fossils distinctive of a Pyalo Stage have been found associated with the *Ostrea*.

(2) To demonstrate the existence of a great thickness of rocks in which the characteristic fossils of the Singu and Kama Stage are found together, the writer has ventured to separate this group of rocks as the " Migyaungye Stage ". To include it in the Singu Stage would involve the addition of a long list of Kama fossils now found in the higher part of the Singu Stage. To include it in the Kama Stage would involve the addition of an equally long list of Singu fossils now found in the lower part of the Kama Stage.

The stages of the marine Peguan therefore now stand :—

5. Kama Stage
4. Migyaungye Stage
3. Singu Stage
2. Padaung Stage
1. Shwezetaw Stage.

to which may possibly be added the Akauktaung Stage, which occurs only in the south of the basin. It is not yet certain whether it is truly a separate later stage or a lateral, shallow water phase of the other stages.

As the writer has repeatedly stated, the palaeontological stages cross the lithological horizons, a feature illustrated for a part of the Peguan region in Fig. 1 and Fig. 2.

III. THE DETAILED LITHOLOGY OF THE MARINE PEGUAN OF BURMA.

It has often been stated that the Pegu System is characterized —at least in its upper part—by a rapid alternation of sands, shales, clays, etc. This is undoubtedly true, but a more precise yet simple method of description has been found possible.

When one observes the sediments closely it is to be noticed that they range from what are, broadly speaking, pure sands (not in the

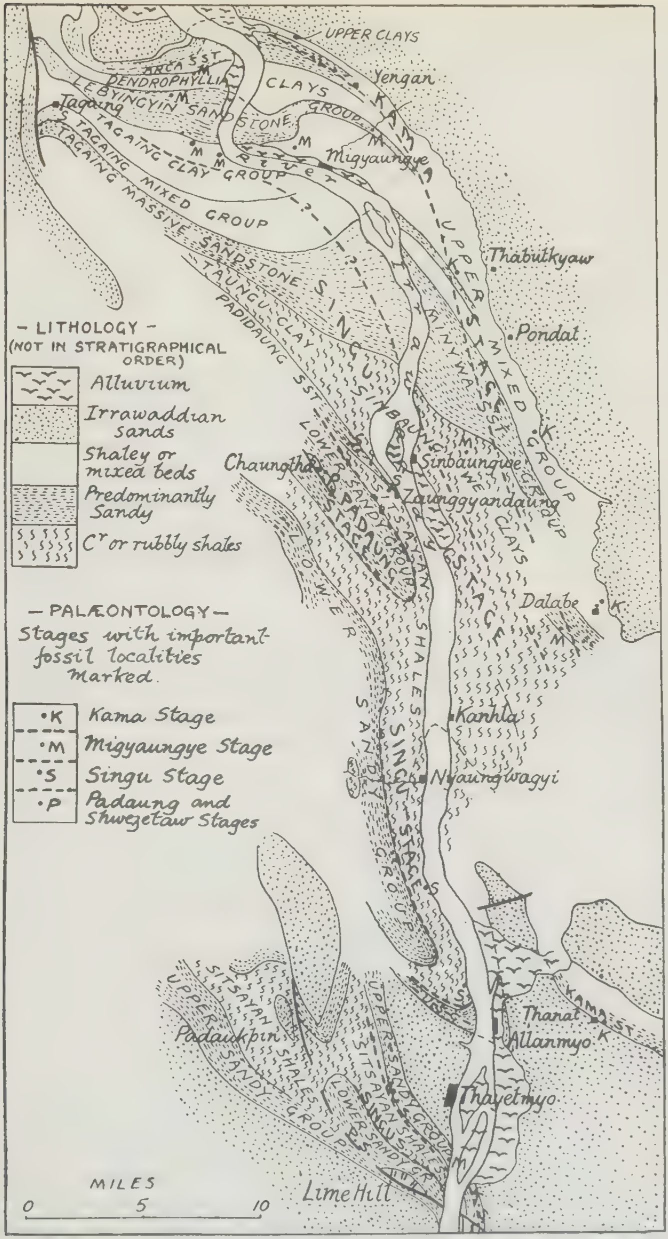

FIG. 1.—Sketch-map of part of the riverine tract of Burma, showing the relationship between lithological horizons and palaeontological stages and indicating the position of sections referred to in the text.

sense understood by the micro-petrologist or the agriculturist) to homogeneous clays. For the most part the intervening stages comprise well-bedded sediments consisting of alternating laminæ of sand and clay. It is found further that the laminæ vary in thickness, sometimes the clay band is the thicker, sometimes the sand. In some cases one has merely a laminated clay in which the laminæ are just separated by a dusting of sand. In other cases the rock is really a banded sand in which the bands are separated by a very thin leaf of clayey material or silt. In either case, as well as in all intermediate stages, one can count the number of double laminæ—i.e. of sand and clay—in an inch thickness of sediment. A simple shorthand nomenclature can be used as follows :—

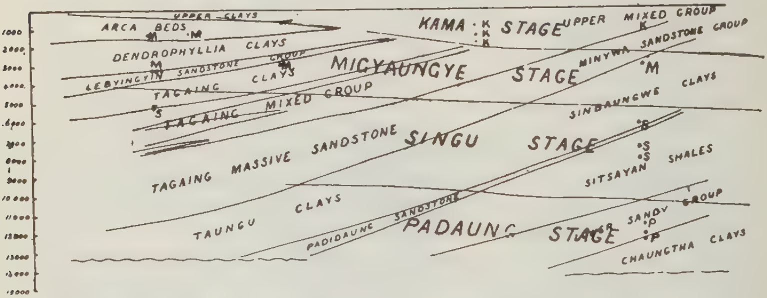

FIG. 2.—Diagrammatic section, drawn approximately to scale, showing the variation in lithology in the Peguan of Central Burma, from north-west to south-east over part of the area shown in Fig. 1. Important fossiliferous localities are shown by dots, and the way in which the palaeontological stages cross the lithological horizons is very marked.

C = Homogeneous unbedded clay.
cc = Banded sediments, almost entirely clayey.
c = Banded sediments, clay predominating.
s = Banded sediments, sand predominating.
ss = Banded sediments, almost entirely sandy.
S = Homogeneous sand.

For the four middle divisions the number of double laminæ per inch may be expressed by an initial figure, thus :—

6c = Banded sediment, clay predominating, with six double laminæ per inch.

Variability is naturally expressed by such formulæ as :—

6–8 c–s = A banded sediment in which either clay or sand may predominate and the number of double laminæ vary from six to eight per inch.

Almost any of the above sediments may be false-bedded (especially the pure sands) and this feature may be expressed by the index letter ^{e} (= entrecroisée ; f.b. is not used because of confusion with fossil-bed) thus :—

S^e = False bedded sand.

The pure clays are often sphæroidal or rubbly (Sitsayan Shale type), and for this characteristic the index letter ^{r} is used thus :—

C^r = Rubbly shale of Sitsayan type.

The writer considers it is difficult to explain the significance of this lamination except as a natural result of an annual variation in the volume and carrying capacity of the river or rivers which were sweeping sediment into the Burmese Gulf. Each double lamina would represent the sediment of a single year, the finer portion being laid down during the river's low water season and the coarser portion during the high water or flood season. It must be borne in mind that the associated fossils are marine, so that the sediments must have been laid down to the seaward side of the river mouth and away from the influence of local or seasonal storms such as cause similar lamination in stream sections at the present day. It may be objected that the Proto-Irrawaddy River which flowed into the Burmese Gulf and deposited these sediments was subjected to bi-seasonal or even multi-seasonal floods, but it is difficult to imagine such meteorological conditions in the Asia of early Tertiary times as would occasion such differences from the present day. The rivers drained from the old land mass of Central Asia, and a monsoon rainfall, if such occurred, would synchronize with or at least augment flooding due to the melting of snows.

It seems reasonable, then, to regard each double lamina as representing one year, and calculations based on this supposition give some interesting results. Quite apart from the actual time value of the laminæ, however, there is a valuable means of comparing thicknesses of strata in widely separated localities. It is superfluous to remark, were it not for the fact that it has been repeatedly done in Burma, how utterly misleading is the direct comparison of thickness of different sediments. It is now obvious from what has been said above that 100 feet thickness of 10 c. took 12,000 years or "season time-units" to accumulate, whereas 100 feet of $\frac{1}{2}$ s. (i.e., sand of which the double laminæ are 2 inches thick) only took 600 years to be deposited. There comes the difficulty then of comparing the non-laminated clays and sands. Now it is found that the C^r grades almost imperceptibly in many sections into 15–20 cc., and from field experience it seems reasonable to assume that the C^r was deposited roughly at the same rate as the 20 cc. This figure has been used in the calculations. The case of S (usually as S^e) is more difficult; fortunately the total bulk is less, and thus not so likely seriously to upset the calculations. Frequently S^e seems to grade into $\frac{1}{4}$–4S, so an arbitrary middle figure 2 has been used.

After counting the laminæ in a few dozen sections one's eye becomes accustomed to general appearance, and the approximate formula at once suggests itself. These lithological details have been noted in most of the hundreds of sections visited; naturally, the records afforded by the more continuous "chaung" or stream sections are the more important.

We may now examine certain objections to this method of comparing thicknesses :—

(i) False bedding. This is mainly restricted to the sands noted above, and does not seriously affect the calculation in other cases, since it is usually possible to follow along the strike to a point where false-bedding is not present.

(ii) Ravinement (local intra-formational unconformities). These are frequent especially in those sediments which have been deposited rapidly. It is almost impossible to allow for them, except in small cases where they are seen to disappear when traced along the strike. However, the calculations based on one stream section can be checked by those from other neighbouring streams and the chances of error reduced.

IV. The Significance of the Seasonal Rhythm.

It has been pointed out above that each double lamina in the Burmese Peguan most probably represents the sediment laid down during one year. The following estimates of the duration of the Peguan are based on the counting of the laminæ. It is admitted at once that the present results are scarcely more than an indication of the possibilities of the method. But the estimates are based, at least in part, on the actual counting of the seasonal bands, and however many the gaps and however rough the calculations and however many the assumptions made it is suggested that the results must be closer approximations to the truth than previous essays in the measurement of time by thicknesses of sediments. Everyone is familiar with the time-honoured calculations based on the present rate of deposition of sediment by such rivers as the Nile. The Peguan laminated deposits show how variable must have been the rate of deposition and illustrate the doubtful value of such calculations.

At present the data for the determination of the duration of Peguan period are extremely scrappy. No complete and continuous section of the Peguan from top to bottom has been found suitable for detailed study. Perhaps the most complete is that in the Sinbaungwe area (for these localities, see Fig. 1) but the calculations are very rough :—

Beds.	*Thickness in feet.*	*Years per inch.*	*Years.*
6. Upper Mixed Group .	2,000	10	240,000
5. Sinbaungwe Clays .	3,000	20	720,000
4. Sandstone band . .	20	—	—
3. Sitsayan Shales . .	3,500	20	840,000
2. Lower Sandy Group .	3,500	6	250,000
1. Chaungtha Shales .	500	20	120,000
			2,170,000

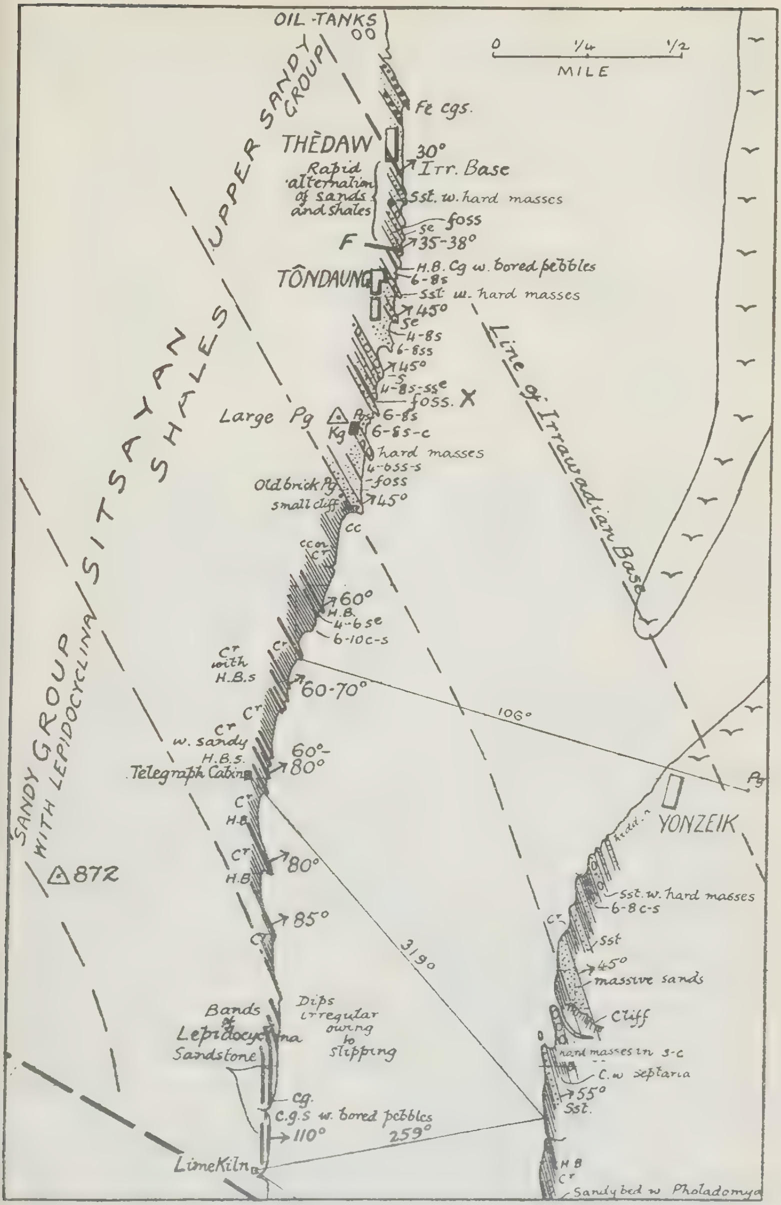

FIG. 3.—Sketch-map of the Irrawaddy River south of Thayetmyo, showing details of the Peguan.

The top of this section is probably rather below the middle of the Kama Stage. The base is at an unknown horizon (probably in the lower part of the Padaung Stage), but judging by the total thickness of the Peguan to the west around Yenanma, etc., it is probably at no great distance from the base. A minimum duration of 2½ millions of years for the Peguan is thus indicated.

Turning to the Thayetmyo district (where excellent sections are exposed on the banks of the Irrawaddy, Fig. 3), the succession is :—

	Feet.	*Average rate.*	*Years.*
Upper Sandy Group	2,250	5·6	153,190
Sitsayan Shales	4,030	20	1,000,000
Lower Sandy Group	2,370	10	250,000
Shales	(?) 1,400	(?) 15	250,000
Limestones of Lime Hill	(?)	(?)	(?)
Sub-Limestone beds	(?)	(?)	(?)
			1,653,000 plus

Here again the upper beds are probably in the lower part of the Kama Stage, and a duration of rather over two million years is suggested for the Peguan period. Another calculation may be based on the beds exposed in the Dalabe Chaung, and to the west of the river in the Kadin Chaung. Unfortunately the Sitsayan Shales are undulating and hence the thickness is uncertain.

	Feet.	*Average rate.*	*Years.*
Upper mixed Group	2,300	8	220,800
Sitsayan Shales	(?) 6,000	10	1,440,000
Lower Sandy Group	6,336	7	529,300
Lower Shaley Group	500	20	120,000

Again over two million years for the whole Peguan is indicated.

In the west of the Minbu and Thayetmyo Districts we have complete sections from the top to the bottom of the Peguan but the writer has not had an opportunity of studying any in detail. The total thickness is between 12,000 and 13,000 feet in the Pwaybwe area, but owing to the increase in beds of Sitsayan Shale type, decreases southwards. Taking a section from Obogôn to Kyaukpôn, for example, it is only about 9,000 feet but roughly three-quarters appears to be of Sitsayan type. This gives, at one inch per twenty years, at least 1,620,000 years. Allowing 1 inch per fifteen years —the sediments are fine-grained—for the remainder this gives 405,000—a total of roughly two million years for the duration of the whole Peguan in this locality. There is here, however, strong evidence for the pre-Irrawaddian removal of the higher beds.

It will possibly be remarked that in the riverine sections mentioned above the Kama Stage has not attained its full thickness, which is only seen further south in the neighbourhood of Kama. But the beds are mainly of a sandy type, and the increase in number of years is not proportional to the increase in thickness. The detailed investigation of the upper mixed sediments in the Myebya

Chaung near Migyaungye furnishes data of importance. As these beds are typical of the rapidly alternating type of Pegu rocks, it will be of interest to record that the average rate of deposition was found to be, after careful calculation, 1 inch in 5·1 years for the upper 1,950 feet of strata, or one inch in 4·5 years for the 1,190 feet actually studied in detail. Figs 4 and 5 give details of this section.

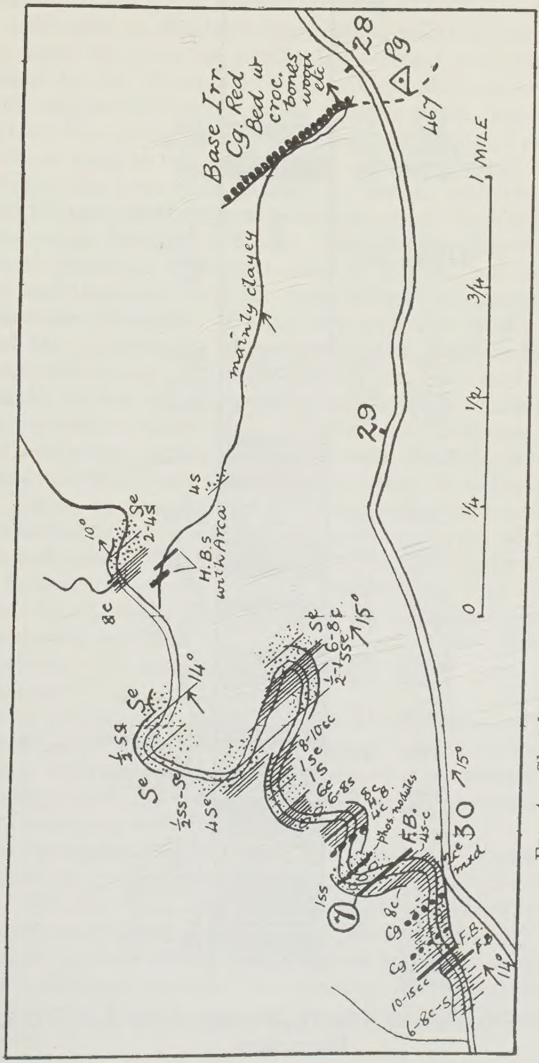

FIG. 4.—Sketch-map of the Myebya Chaung, north-east of Migyaungye (upper part of Peguan).

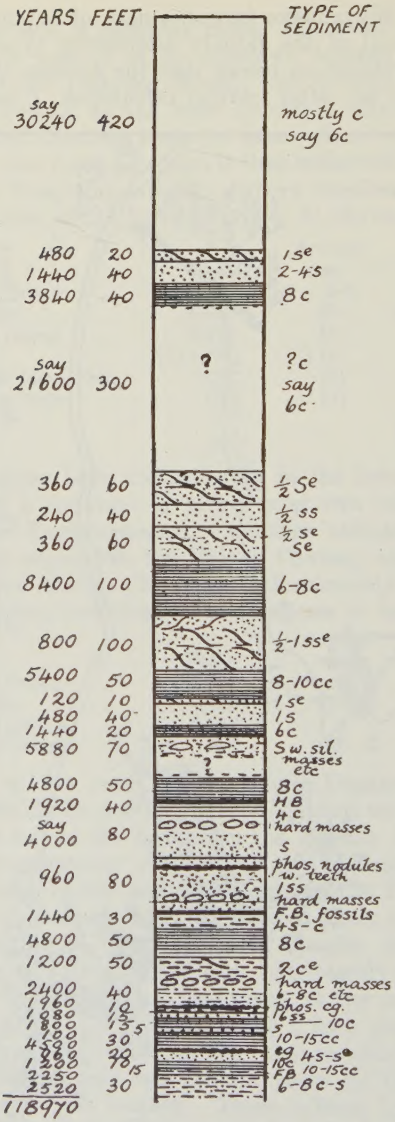

FIG. 5.—Vertical section of the Upper Peguan in the Myebya Chaung, Migyaungye.

As far as these extremely rough estimates go, one would say that the time occupied by the deposition of the beds from the base of the Peguan, i.e. the base of the Oligocene, to the Kama Stage was about 2½ million years. If palaeontological correlations are correct this represents the duration of the whole of the Oligocene and the greater part of the Miocene periods.

However, the interest of these remarks lies rather in the future possibilities of the method than in the present results. The writer remembers having noticed banding of a similar type in very many sediments in England, but before studying the Peguan of Burma failed to grasp its significance. Apart from the examples mentioned by Dr. Evans there are innumerable others which will no doubt suggest themselves to the reader's mind. Since his return to England the writer has only had the opportunity of re-examining two sets of beds in the light of the Burmese work. Mr. S. W. Wooldridge has been kind enough to discuss with the writer the so-called Claygate beds or passage beds between the marine Ypresian and continental Ypresian in Essex. There the banding is comparable in general character with that seen in Burma, but is much less regular, and the laminæ are far more difficult to count than in the best Burmese examples. During the past few weeks the writer has had the opportunity of examining the Pre-Cambrian Shales of Jersey which are, as Dr. G. H. Plymen has noted, beautifully laminated. In the examples studied the average number of double laminæ per inch is about ten. In these beds, of course, the whole mass is hardened, consolidated and much faulted and fractured.

As pointed out above, there is good reason to believe that each double lamina in the Peguan of Burma represents one year. It is not possible to say the same with equal certainty of the laminæ in other sediments. Each case must be decided on its own merits. Where lamination occurs through hundreds of feet of sediment there can be no doubt that it represents a seasonal phenomenon. If the seasonal period is not a year, it is far more likely to be a shorter period (i.e. more than one flood period per year) than a longer one.

There is evidence in some deposits of rhythmic sedimentation on a much larger scale, often superimposed on the normal rhythm. The writer does not consider the evidence is at present sufficient to speculate upon the meaning of such major rhythms and their possible connexion with sun-spot cycles.

All geologists are familiar with the wonderful results obtained by De Geer by counting the laminæ of the fluvio-glacial clays of Sweden. He has been able to date with considerable accuracy certain important events in the glacial history of Sweden. Bearing this in mind, perhaps it is not too much to hope that as the detailed study of lamination spreads the duration of the various periods of the Geological Column may be determined with some approach to accuracy.

V. Some General Conclusions.

Amongst the many instructive lessons to be drawn from this study, the following may be specially noted :—

1. The duration of the Oligocene and half of the Miocene is

probably in the neighbourhood of 2½ million years. This figure is not inconsistent with the results obtained by the study of radioactive phenomena in igneous rocks.

2. The rate of deposition of various typical sediments is of interest to note. A comparatively fine-grained sand may have been piled up at the rate of a foot in twenty-five years, whilst numerous calculations as to the rate of deposition of alternating sands and clays give an average round about a foot in sixty years. Even a homogeneous clay may be laid down as rapidly as a foot in 200 years or even less. This applies to clays with a comparatively deep-water *Pleurotoma* fauna. When dealing with series of clay in other parts of the world than Burma it is obviously unwarrantable to assume unlimited time for the deposition of a small thickness of sediment. This gives point to the remarks which the writer has made elsewhere that the time occupied by a hemera may have been insufficient for the migration of a characteristic species to all parts of even a single basin of deposition and certainly not from one basin to another.

3. A million years has sometimes been regarded as a mere bagatelle in geological time. In Burma it has been sufficient for the deposition of between 5,000 and 10,000 feet of sediment.

4. Due attention to the counting of laminæ in sediments may eventually render it possible to determine the duration of geological periods with considerable accuracy.

ADDENDUM.

When this paper was read before the British Association, several points of interest, not directly answered in the paper, arose in the discussion. Professor Boswell pointed out that some writers had claimed that it was possible to determine the order of deposition of series of ancient banded sediments by saying that the coarse sediment of the flood season graded upwards gradually into the fine sediments of the low water season which were in turn *abruptly* succeeded by the coarse sediments of the following flood season. The author could not say that this gradation was the invariable rule, but it was certainly common. Professor Kendall asked whether the sedimentation might not be complicated by simultaneous deposition from more than one distributary of the river. It was held that the sediments would show indications of such cross currents and that it was immaterial if the same area of deposition came under the influence of different distributaries in the course of years. Dr. Greenly asked if there was palaeontological evidence of non-sequences. The author pointed out the broad nature of the " stages " recognized. Dr. Evans asked if there was evidence of fluctuations in the flood-strength from year to year. Such is the case. It was generally agreed that the duration of years obtained was a minimum, it being impossible to evaluate the duration of periods of non-deposition.